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TRANSFER OF OXYGEN IN CONSTRUCTED WETLANDS APPLIED TO WASTEWATER TREATMENT

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TRANSFER OF OXYGEN IN CONSTRUCTED WETLANDS APPLIED TO WASTEWATER TREATMENT

This graduation work was considered adequate for obtaining the title of Sanitary and Environment Engineer, and approved in its final version by the course of Sanitary and Environmental Engineering.

Florianópolis, Tuesday 26th November 2019.

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This work is dedicated to my UFSC colleagues, my parents, and the people and teachers who helped me graduate from UFSC.

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All you need to do
Is to decide to go, then it’s almost done.

(Tony Wheeler, 2015)

Tout ce que vous avez à faire,
C'est de décider de partir et le plus dur est fait.
(Tony Wheeler, 2015)

ABSTRACT

Constructed wetlands are part of the decentralized treatment alternatives for wastewater. It is a technology mainly used in rural areas and research in the field is numerous. GESAD is one of the laboratories working on the subject. The raw influent comes directly from the sewerage of the Pantanal neighborhood basin, then it is guided to a septic tank before arriving in the constructed wetlands. During a determined time, the effluent is discharged on the surface of the filter, in the most homogeneous way possible. The fluid is infiltrated, oxygen exchanges are greater and the oxygenation reactions take place. Nitrification is rolled up in the upper part of the filter, while in the lower zone which is saturated, there is denitrification. The effluent leaves the filter and it is at this moment that measurements are made. These measurements make it possible to obtain the masses of oxygen leaving the filter, consumed and therefore entering. Knowing the surface of the filter it is possible to deduce the flow of oxygen and the yield. The measurements were carried out between March and October 2019. This makes it possible to cover a large period of time. VFCW-PS removal efficiency has increased since 2017, with 98.83% DO removed, 88.6% of COD, 83.4% of NH_4^+ and 57.8% of TN. Initial DO concentrations (8.21 $mg.L^{-1}$ on average during the first pulse and 7.12 $mg.L^{-1}$ during the third pulse) indicate that the filter cannot fully recharge during the 90 minute rest. Therefore, oxygen flow is higher during the first pulse because it is fully recharged with oxygen. The average oxygen intake per unit area per day is 36.23 $g.m^{-2}.d^{-1}$. This result is enthusiastic because it is comparable to VFCW and Hybrid filters.

Keywords: Wastewater. Treatment. Oxygen transfer. Constructed Wetlands.

RESUMO

Os Wetlands Construídos fazem parte das alternativas de tratamento descentralizadas para os esgotos. É uma tecnologia usada principalmente em áreas rurais e as pesquisas no campo são numerosas. O GESAD é um dos laboratórios que trabalha sobre o assunto. O efluente vem diretamente da rede de esgoto do bairro Pantanal, depois é encaminhado para uma fossa séptica antes de chegar na estação de tratamento, então nos Wetlands Construídos. Durante um tempo determinado, o efluente é descarregado na superfície do filtro, da maneira mais homogênea possível. O líquido é infiltrado, as trocas de oxigênio são maiores e as reações de oxigenação ocorrem. A nitrificação ocorre na parte superior do filtro, enquanto na zona inferior que está saturada, há desnitrificação. O efluente sai do filtro e é nesse momento que são feitas as medições. Essas medições permitem obter as massas de oxigênio que saem do filtro, consumidas e, portanto, entrando. Conhecendo a superfície do filtro, é possível deduzir o fluxo de oxigênio e o rendimento. As medições foram realizadas entre março e outubro de 2019. Isso permite cobrir um grande período de tempo. A eficiência de remoção do WCFV-PS aumentou desde 2017, com 98,83% de remodelação OD, 88,6% de DQO, 83,4% de NH_4^+ e 57,8% de TN. As concentrações iniciais de OD (8,21 $mg.L^{-1}$ em média durante o primeiro pulso e 7,12 $mg.L^{-1}$ durante o terceiro pulso) indicam que o filtro não pode recarregar completamente durante o os 90 minutos de descanso. Portanto, o fluxo de oxigênio é maior durante o primeiro pulso, porque é totalmente recarregado com oxigênio. A entrada média de oxigênio por unidade de área por dia é de 36,23 $g.m^{-2}.d^{-1}$. Este resultado é entusiasmado porque é comparável aos filtros WCFV e Hibrid.

Palavras-chave: Esgoto. Tratamento. Transferência Oxigênio. Wetlands Construídos.

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LISTA DE ABREVIATURAS E SIGLAS

General

ABNT	Associação Brasileira de Normas Técnicas
CASAN	Companhia Catarinense de Águas e Saneamento
CW	Constructed Wetlands
GESAD	Grupo de Estudos em Saneamento Descentralizado (UFSC)
HFCW	Horizontal-Flow Constructed Wetlands
IBGE	Instituto Brasileiro de Geografia e Estatística
LAPOA	Laboratório de Potabilização das Águas (UFSC)
NBR	Normas Brasileiras/Brazilians normes
UFSC	Universidade Federal de Santa Catarina
VFCW	Vertical-Flow Constructed Wetlands
VFCW-PS	Partially Saturated Vertical-Flow Constructed Wetlands

Chemicals elements

BOD_5	Biochemical Oxygen Demand (5 days)
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
NH_4	NH_4 Ammonium
NO_X	Nitrogen Oxides (most relevant: NO_2 and NO_3)
NO_2	Nitrogen dioxide
NO_3	Nitrate
O_2	Dioxygen
SS	Suspended Solid
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen

Physical values

A	Area	m^2
C	Concentration	*mg/L*
CR	Removed Charge	$L.m^{-2}.h^{-1}$
δ	Approximation error	*%*
ef	Efficiency	*%*
ef_e	Elimination Efficiency	*%*
h	Water height	*cm*
j	Flow of oxygen	$g.m^{-2}$
		$g.m^{-2}.h^{-1}$
		$g.m^{-2}.d^{-1}$
m	Mass	*mg*
		g
M	Total mass	*mg*
		g
n	Pulse number	-
Q	Flow	*L/min*
θ	Correction coefficient	-
t	Time/duration	*s*
		min
		h
V	Volume	*L*

SUMÁRIO

1 INTRODUCTION

This graduation work is carried out within the framework of the double degree UFSC-ENGEES recently set up. It was carried out in the GESAD laboratory, which works on wastewater treatment by decentralized processes. The main type of treatment is the constructed wetlands sector.

The collection and treatment of wastewater is a public health issue. In Brazil, according to the *Agência Nacional de Águas* (ANA, 2019), just under half of the country's municipalities (43.45%) are connected to the sanitation network. This number means that another modality of sanitation must be studied to reach the universalization of sanitation.

In rural areas, wastewater treatment is mainly decentralized and individual. The objective is to treat the effluent on the spot in order to avoid a transport sometimes long and expensive. Septic tanks and anaerobic filters are well known and used technologies. However, new technologies have been the subject of extensive research. This is the case of constructed wetlands.

Constructed wetlands are designed to treat a several types of wastewater, highlighting the domestic and sanitary wastewater. The natural action of the macrophytes such as *Thypha domingensis* combined with the bacterial activity in the soil and in the filter medium, makes it possible to reduce almost all the BOD_5 and SS. There are vertical, horizontal and sometimes combined plant filters called hybrid system. This study works only with a modification of the classical vertical flow constructed wetlands, called partially saturated vertical flow constructed wetland - VFCW-PS.

This work seeks to know the dynamics of oxygen consumption associated with a specific mode of operation in VFCW-PS. The use of the organic load as a design criterion for a VFCW-PS seems appropriate for determining the dynamics of O_2 consumption associated with the oxidation of organic matter and NH_4. The objective is to perform an oxygen balance in order to know the flow of oxygen in the system and therefore the efficiency of deoxygenation.

The work is divided into three stages. The first step is to measure the volume and OD concentration of the effluent at the filter outlet. It is possible to calculate the total mass of outgoing oxygen. These results will then be combined with measurements made in parallel by another GESAD laboratory team (TN, TKN BOD and COD measurements) at the input and output of the same filter. This is the second step. Then, it is possible to know the amount of oxygen consumed in the filter. The sum of these two results makes it possible to calculate the quantity of oxygen entering the filter, and thus the flow of oxygen and the efficiency.

2 OBJETIVES

This present TCC is carried out within the GESAD laboratory, *Grupo de Estudos em Saneamento Descentralizado*, in Florianopolis, S.C. - Brazil.

2.1 General objetives

The main objective is to carry out a transfer and oxygen consumption report throughout the wetland.

2.2 Specific objetives

- Measure the concentration of oxygen in the effluent in order to know the total mass of oxygen coming out of the VFWC-PS during a pulse.
- Determine the amount of O_2 transferred to the VFWC-PS unit by convective and diffusive processes (amount of OD in the filter, output, input and consumed).
- Determine the average flow of affluent OD to the VFCW-PS unit by convection.
- To compare results with existing models (Horizontal-flow, Vertical-flow and Hybrid system).
- To adjust the settings to increase and to stabilize the performances

3 BIBLIOGRAPHIC REVIEW

3.1 Decentralized wastewater treatment system

Nowadays, when the population tends to move towards the big cities, to concentrate to occupy as little space as possible, the collection and treatment of sewers is an environmental, health and economic issue (ANTOINE, 1997).

In very densely populated areas, the choice to centralize, that is to say to use a collective system called dynamic, is an interesting solution according to the stakes mentioned above. Otherwise, in rural areas, using an individual or static system is more consistent. In general, decentralized systems are those that collect, treat and dispose of wastewater in a place close to their generation, unlike traditional centralized systems. Some authors classify centralized or decentralized systems by number of inhabitants served, organic wastewater load and / or daily volume generated (TONETTI et al., 2018). This individual system is used in small wastewater treatment units, which aim to solve the problem with reduced costs (HOFFMAN et al., 2004; LANZER & WOLFF, 2005). It is used for the treatment of small flows, such as houses, condominiums, isolated buildings and small communities, where effluents can be absorbed and treated on site or in other units.

The Brazilian standard NBR 7229/93 presents the criteria necessary for the correct design, construction and operation of septic tanks. This standard was completed by NBR 13696/97 (ABNT, 1993, 1997). The latter was developed with the aim of expanding and detailing viable technical solutions for the complementary treatment and final disposal of septic tanks. Treatment in septic tanks involves physical and biological mechanisms of sedimentation and anaerobic digestion, respectively. The increase in waste resulting from this digestion and the rate at which this process takes place regulate the rate of accumulation, which will determine the frequency of cleaning the septic tank (PHLIPPI, 1997). Technical standards are a recommendation and do not preclude the use of other more compact, economical and efficient processes.

Several non-standard treatment technologies, such as constructed wetlands and sequential batch reactors, are used in Brazil and France, for example (ABNT, 1997; MOLLE, 2012).

3.2 Constructed Wetlands

The deterministic approach, since the beginning of the 2000s, has made it possible to optimize treatment streams in terms of sizing and management. On the other hand, it doesn't always respond to the societal demand when it comes to changing the sectors towards fields of application (rainwater treatment, industrial water, treatment of emerging pollutants, etc.) or designs (research of compactness) very different.

Although the reed-planted filter system provides reliable aerobic treatment, the research conducted in recent years has made it possible to develop the sector to respond to previously unresolved problems (unitary network, nitrogen, phosphorus, process combination, reduction of the footprint ...). The last ten years in France, the filter chains planted with reeds have become the favorite option of small communities and currently treat nearly 15% of the French's waste water (MOLLE, 2012).

The evolution of research over the last twenty years accelerates the acquisition of knowledge and, as a result, expands the field of application. The use of extensive techniques in the future should continue to evolve in view of the importance of developing environmentally-friendly wastewater systems (MACHADO e Al 2007).

There are two categories of Constructed Wetlands (CW). There are free-flowing or surface-flow systems and underground flow systems (filters planted with macrophytes). In these two large classes there are subgroups, that is CWs with different configurations and operating principles associated with objectives such as carbon reduction, nitrification, denitrification, retention / removal of phosphorus, among others (DIAS, 2015; PHILIPPI & SEZERINO, 2004).

In this work the filters used are of the underground flow systems type. The purification is carried out according to the principle of biological purification mainly aerobic in fine to coarse granular media. There is no regular renewal of the filtering mass or biological sludge evacuation (POULET & TERFOUS, 2004). There are two types of filters planted, depending on the direction of flow but there are three configurations:

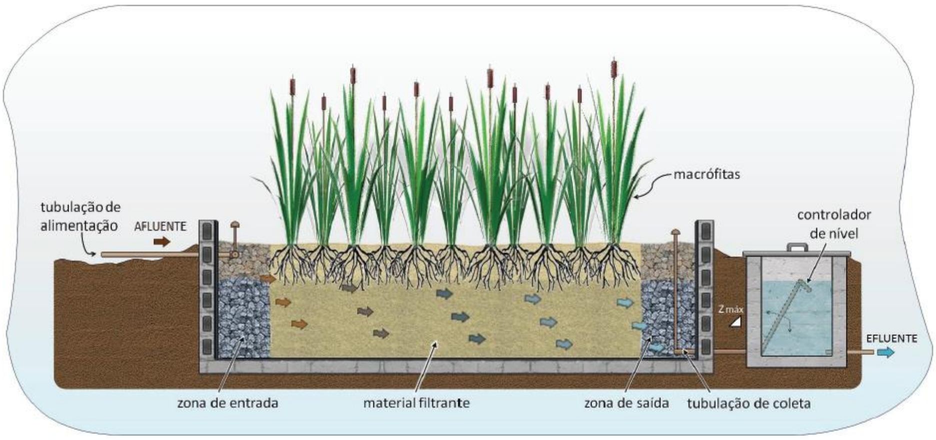
- Horizontal flow filters (HFCW)
- Vertical flow filters (VFCW)
- Hybrid configuration (VFCW + HFCW)

Stations using constructed wetlands are often a combination of parallel and serial beds. Having 3 identical basins in parallel makes it possible to roll around, and to let the bacteria, the filtering materials and the macrophytes rest. We avoid all kinds of saturation and the yield is better.

3.2.1 Horizontal Flow Filters (HFCW)

The planted filter of macrophytes is called "horizontal flow" because the wastewater enters the inlet zone and flows through the pores of the filter material along a more or less horizontal path to the exit zone (Figure 1). Wastewater encounters aerobic, anoxic and anaerobic zones. The aerobic zones are located near the roots and rhizomes. During the passage of wastewater through the rhizosphere, they are degraded by the action of microorganisms and by physical and chemical processes (OLIJNYK, 2008). Oxygen required for aerobic degradation is supplied directly from the atmosphere by diffusion or oxygen leakage from rhizomes and roots to the rhizome. (IWA, 2000)

Figure 1: Schematic representation of a HFCW

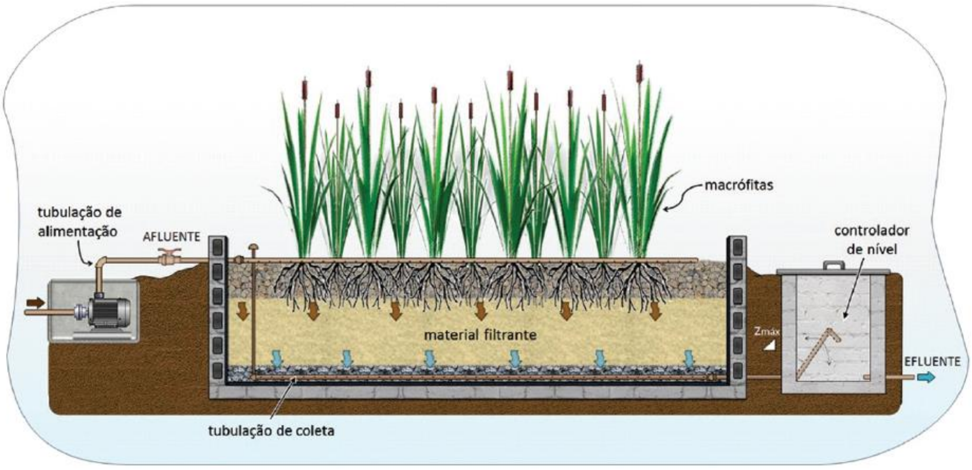


Source : GESAD (SEZERINO et al., 2018)

3.2.2 Vertical Flow Filter (VFCW)

The filters planted with vertical flow macrophytes are fed to the surface in waste water, in a punctual manner, and are progressively evacuated vertically through the filter bed (Figure 2). The outlet is nothing other than a drainage system at the bottom of the filter. Once all wastewater has been removed, the free filter bed allows air to enter the bed. Thus, during the next feeding, the wastewater seizes the air from the pores of the bed and, together with the aeration caused by a fast feeding, proceed to a good oxygen transfer. This good oxygen transfer allows the decomposition of the BOD and the nitrification of ammoniacal nitrogen. As with horizontal flow filters, the plants will transfer some of the oxygen to the rhizosphere, but this is very small compared to the oxygen transfer created by the system assay. (IWA, 2000)

Figure 2: Schematic representation of a VFCW



Source : GESAD (SEZERINO et al., 2018)

3.2.3 Partially saturated vertical flow constructed wetland - VFWC-PS

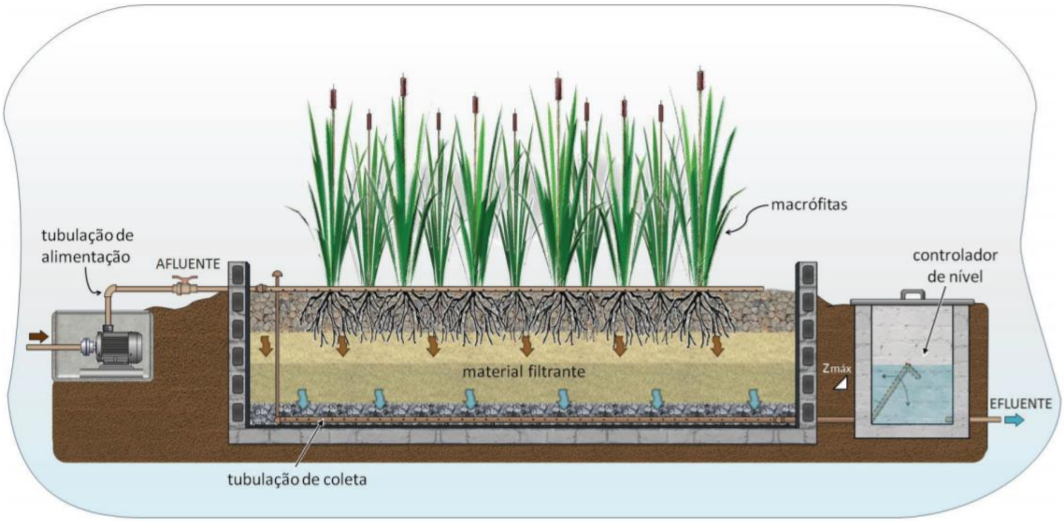
One of the most common techniques for achieving complete removal of nitrogen, suspended solids and organic matter is the combination of two types of series filter: VFCW and HFCW. It is the hybrid system. However, this requires large areas and therefore significant costs.

The research is now focused on other strategies to have similar efficiency for a reduced ground surface occupation. The modified VFCWs are among solutions, such as:

- VFCW with rest units - French model, (MOLLE et al., 2006)
- VFCW with fill and drain cycles, (WU et al., 2011)
- VFCW with aeration, (HEADLEY et al., 2013)
- VFCW with a saturated background (KIM et al., 2014)

The last option, Saturated wetlands (Figure 3), are designed to increase denitrification rates in upland wetlands because the bottom saturated layer provides anoxic zone formation, meeting the requirements of the biological process Diagram illustrating VFCW-SB (SEZERINO et al., 2018).

Figure 3: Schematic representation of a VFCW-PS



Source : GESAD (SEZERINO et al., 2018)

The main difference between VFCW-SB and VFCW is a hydraulic modification made to allow for greater nitrogen removal in a single unit, without additional energy increment and in the smallest area. In this model, the saturation results in the creation of anaerobic / anoxic conditions at the bottom of the VFCW-SB. Thus, in a single treatment unit, there is:

- aerobic conditions (Top) which favors the oxidation of organic matter and nitrification.
- anaerobic / anoxic conditions (Bottom) which favors the reduction of organic matter and denitrification. (SEZERINO et al., 2018)

3.3 Functions of macrophytes

The plant *Typha domingensis* is a species of monocotyledonous perennial plant of the genus *Typha* and of the family *Typhaceae* (Sarr, Thiam, & Tidiane Bâ, 2009). Macrophytes have an aesthetic and mechanical role first, but not only. They indirectly contribute to the degradation of organic matter in the raw effluent.

Root and rhizome growth help to reduce the clogging effect of the filters. The small particle size of the substrate (sand and gravel) combined with the high organic matter content is conducive to creating these blockages. This root development increases the attachment surface for the development of microorganisms. To this is certainly added a stimulating effect of activity and density increase of microorganisms. But this is still hypothetical because there is still very little research in the field (MOLLE et al., 2005).

The foliar cover preserves the surface of the desiccation filters. The shade it provides allows bacteria to grow, contributing to the mineralization of organic matter. Evapotranspiration helps to decrease the outgoing volume, even if it remains negligible.

In a more general way the filter medium, thanks to the presence of the roots, has a great diversity of species (bacteria, protozoa, invertebrates) whose presence depends closely on the organic load and the oxygen renewal conditions. These organisms also make it possible to reduce the populations of fecal bacteria by acting as a predator.

3.4 Function of Material Filtrate

The filter material is primarily used to filter, as the name suggests. But it is also the element that supports macrophytes. In addition to acting physically during the filtration process, this material is also involved in most biochemical reactions that develop within built-up wetlands, as it supports the development of the microbial biofilm, in addition to the process. of adsorption of pollutants (chemical phenomenon) on their grains.

Ideally, the filter material should have characteristics that reconcile good permeability across the pores between the grains constituting the filter material, as well as a good potential for reactive adsorption. The permeability must be such that it allows the suspended solids present in the wastewater to be filtered rapidly, avoiding the clogging phenomenon.

The choice of material is a weighting between the economic factors and the adsorption capacity of the inorganic compounds. The most common practice is to choose sand and gravel in order to extend the life of the system. The literature contains recommendations for the use of sands and gravel for the secondary and tertiary treatment of domestic wastewater (PELISSARI, 2017; SEZERINO et al., 2018) .

3.5 Microbiological activities

The action of microorganisms is recognized as the main agent in the treatment of biodegradable compounds in sewers. In built wetlands, the diversity and abundance of microorganisms are important, especially for the group of bacteria. The emergence and predominance of specific microorganism communities is closely related to the surrounding environmental conditions, in terms of oxygen and carbon availability, temperature, redox potential, and carrier material, which is responsible for the fixation of the fixing bacterial communities, thus forming the biofilm. (SEZERINO et al., 2018)

The biofilm can be defined as a set of microorganisms and extracellular products that adhere to a solid support, forming a thick and thick layer, with an external structure not completely uniform and uniform. (JOHN & EDUOK, 2018)

The aerobic regions will be responsible for the oxidation of ammoniacal nitrogen to nitrites, then to nitrates. Denitrification will occur in the anoxic layer and will occur in the anaerobic regions the formation of organic acids and reduction of sulfates.

Knowing that certain groups of micro-organisms develop according to the type of environment, whether it is rich or absent in oxygen (unsaturated or saturated in wastewater), with a low or high organic charge or with a high or low content in nutrients. It is possible to design wetlands constructed in such a way that these pollutants are more efficiently removed by specific groups of microorganisms.

4 MATERIAL AND METHOD

4.1 Study area

The present work is carried out within the Research Group on Decentralized Sanitation (GESAD). Since its creation in 2004, the laboratory publishes and researches methods of treatment and sanitation of domestic and agro-industrial wastewater through the use of Constructed Wetlands. Some research is on the reuse and segregation of residential waste water.

This work is directly related to the thesis of Léandro Bassani, who is studying the understanding of oxygen transfer within a vertical plant filter designed for 5 people (7.5 m² surface area). The sewers used come from the UFSC, the Pantanal neighborhood basin. The study period covers the months of February to October 2019. It lacks the summer period, but the least adequate conditions, which are at the lowest temperatures, are studied.

4.2 Station of treatment of wasted water

4.2.1 The experimental station

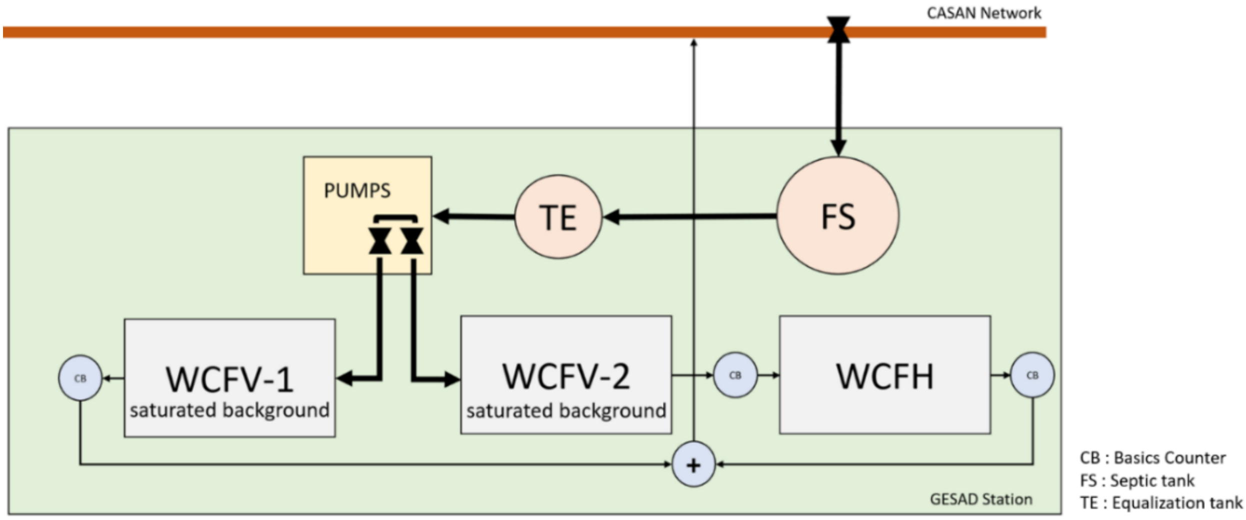
The station of the GESAD is located on the UFSC campus in Florianópolis. The climate is hot and humid, with heavy rains at the beginning of the year and a drier period in winter. There are three filters planted: two verticals and one horizontal. Initially the station was composed of a Partially saturated vertical flow constructed wetland and a combination of two filters: first vertical and then horizontal. In September the GESAD modified the vertical filter in VFCW-PS. Thus, the laboratory has two equal filters, allowing the collection of more data. The figure 4 is a picture taken from the station. On the left is the saturated vertical filter, in the center the second VFCW-PS and on the right the horizontal filter (HFCW).

Figure 4: Experimental station of GESAD

Source: Author

The wastewater comes from the Pantanal neighborhood basin but the GESAD has an exceptional authorization to access the effluent. It is pumped to an upper reservoir to have a first vertical flow. It then flows to a septic tank (FS) that stores the solids and paper that turn into sludge and gas. The next element is the equalization tank. The effluent is mixed with the previous effluents in order to be as homogeneous as possible. After that, there are two pumps that carry wastewater to the planted filters. Once the treatment is completed, the effluent returns to the Pantanal Nieghborhood Basin, where it comes from. The figure 5 show the way the waste water follows.

Figure 5: Layout of experimental wetlands of GESAD / UFSC.



Source: Author

4.2.2The Vertical-Flow Constructed Wetlands with saturated background

The VFCW-SB was constructed according to the following indications and Table 1. The first layer of filter material is composed of 5 cm thick gravel, where the tributary distribution pipe was laid, followed by a layer 60 cm of coarse sand and finally a last layer of gravel of 5 cm where is the collection pipe.

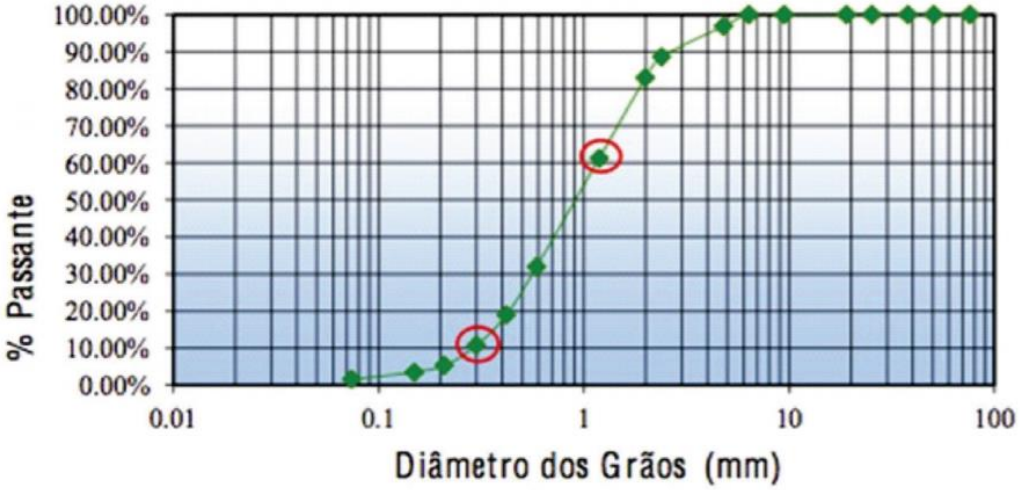
Table 1: Parameters of the constructed wetland with saturated bottom

Parameter	*VFCW-PS dimension*
Built height (m)	0,81
Useful height (m)	0,70
length (m)	3,30
width (m)	2,3
Saturation height (m)	0,4

Source : Adapted from GESAD (SEZERINO et al., 2018)

The filter was filled with gravel and coarse sand, and the porosity of the sand used was 0.35. Figure 6 shows the granulometric curve of the sand used in the constructed wetlands of the GESAD / UFSC experimental station (d_{10} = 0.29 mm, d_{60} = 1.16 mm and U = 4).

Figure 6: Particle size curve of commercial sand. Featured in red d_{10} and d_{60}.



Source : GESAD (SEZERINO et al., 2018)

The planted macrophyte species was *Typha domingensis*. The plants were taken from the flooded terrain of UFSC (natural habitat), located next to the Department of Architecture and Urbanism. In the planting process, the macrophytes were cut 50 cm from their rhizome for adaptation in the new environment, and they were planted with 40 cm spacing between each macrophyte, with population density of 4.20 seedlings/m² in WCVD.

4.3 Methodology

4.3.1 Data gathering

The data collection campaign for this project began in February 2019. The collection is done weekly until October, once on Wednesday morning, once on Thursday afternoon. A measurement collection corresponds to the oxygen concentration measurement in the effluent at the outlet of the filter. The pump supplies the filter for 386 seconds but the time that the wastewater is filtered prolongs this duration. In general, it takes around 90 minutes for the output rate to be close to zero. In rainy weather flows are stronger, the concentration lower, and a constant minimum flow is observed. The dates and times of feed pulses are given in Table 2.

Table 2: Days and times of the alimentation of the VFCW-PS filter

Time	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*	*Sunday*
8:00	-	pulse	pulse	pulse	-	-	-
11:00	pulse	pulse	pulse	pulse	-	-	-
14:00	pulse	pulse	pulse	pulse	-	-	-
17:00	pulse	pulse	pulse	-	-	-	-

Source: Author

The laboratory performs parallel Wednesday morning various complementary and essential analyzes. By combining the measurements, it is possible to obtain a flow, following two data processing. The first allows to know the mass of oxygen per event, the volume of water treated by pulse as well as the concentration in real time and average. the second is based on Platzer's experiments. This work showed how to obtain a mass of oxygen consumed from measurements of DQO and Nitrogen (PLATZER, 1999). It is necessary to combine several masses obtained by the whole GESAD’s team to know the mass entering in the system. The efficiency of the saturated bottom vertical filter is known by a simple In/Out ratio. The methodology is presented more in detail in the following sections that explain the data processing.

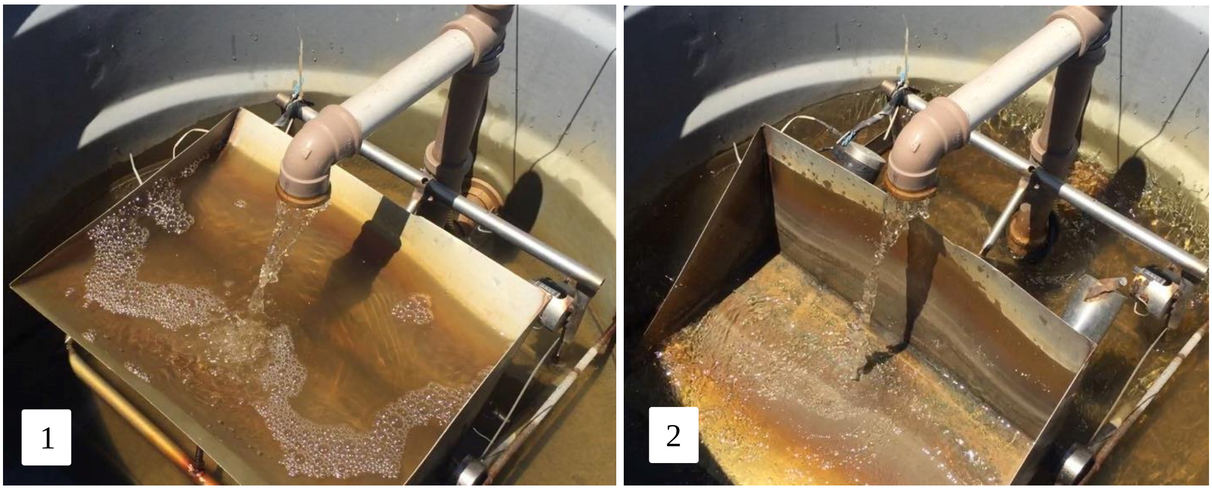
4.3.2 Primary data processing (output)

4.3.2.1 Calibration of volume measurement instruments

The volume measurement is done through a tilting system, where every 7.7 L a meter records a spill. The filter is fed 3 to 4 times a day from Monday to Thursday. During a pulse there is approximately 182 L of sewage which is spilled in 6 minutes and 24 seconds in the filter. It takes about two minutes to observe a flow out of the constructed wetland. Once the outflow has started, in three minutes the flow is at its maximum with about 0.15 L/s. Then, the flow decreases gradually during the next half-hour. In 30 minutes 85% of the pulse volume has already been released. The next 60 minutes the flow is slowed down. It is between one liter per minute and 0.2 L/min.

Below is the scale that counts the volume (Figure 7). On the left (1) it is almost full and ready to rock. On the right (2) it has just tipped over and is about to return to its original position.

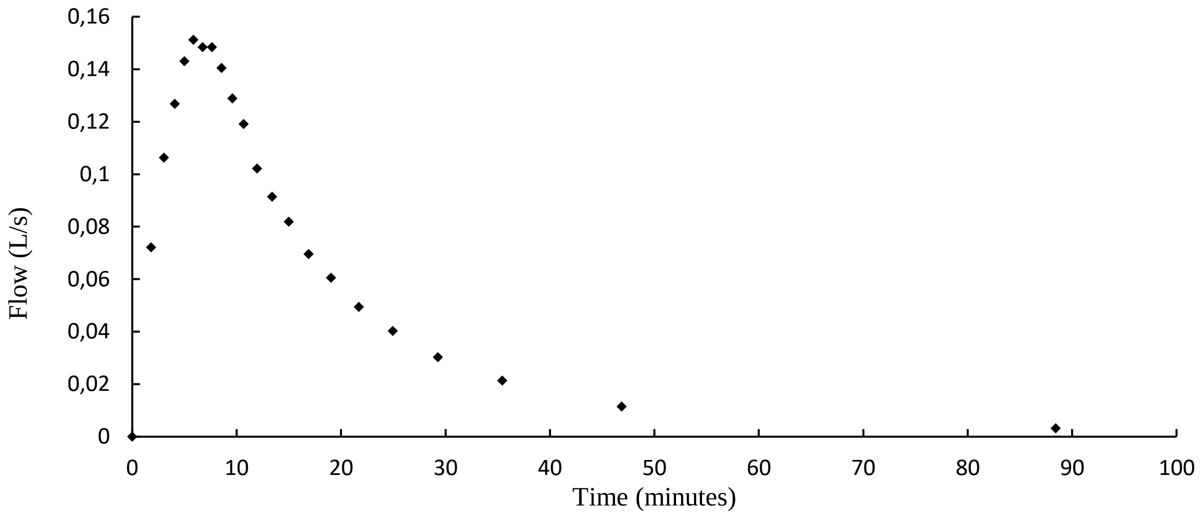
Figure 7: Scale that counts the volume after the filter



Source : Author

The figure 8 shows the flow rate measured by the scale counter as a function of time. Each point represents a spill. The closer the points are, the higher they are in the graph: the flow is then higher. The flow rate presented in the graph is then the average flow observed during the time interval prior to the tilting system.

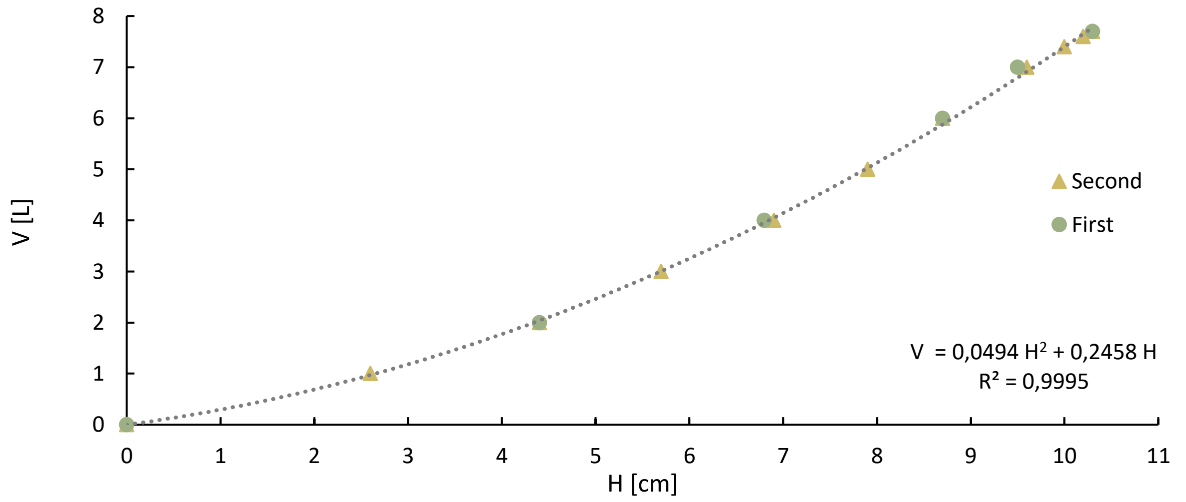
Figure 8: Evolution of the flow during a pulse at the output of a VFCW-PS – 05/16/2019



Source: Author

It was necessary to think of another way to obtain the flow in a quasi-continuous way after 30 minutes of measurement. In other words, it could be interesting to have a measurement every 2 or 4 minutes. The solution adopted is to measure the height of water in the tilting system. A volume-water height correlation is necessary. This is the calibration of the volume measurement tool (Figure 9). Two calibrations were performed. The first in February 2019, and a second in May 2019. The second was made with more points in order to be more specific.

Figure 9: Calibration Curves to measure the volume - Ratio between H and V



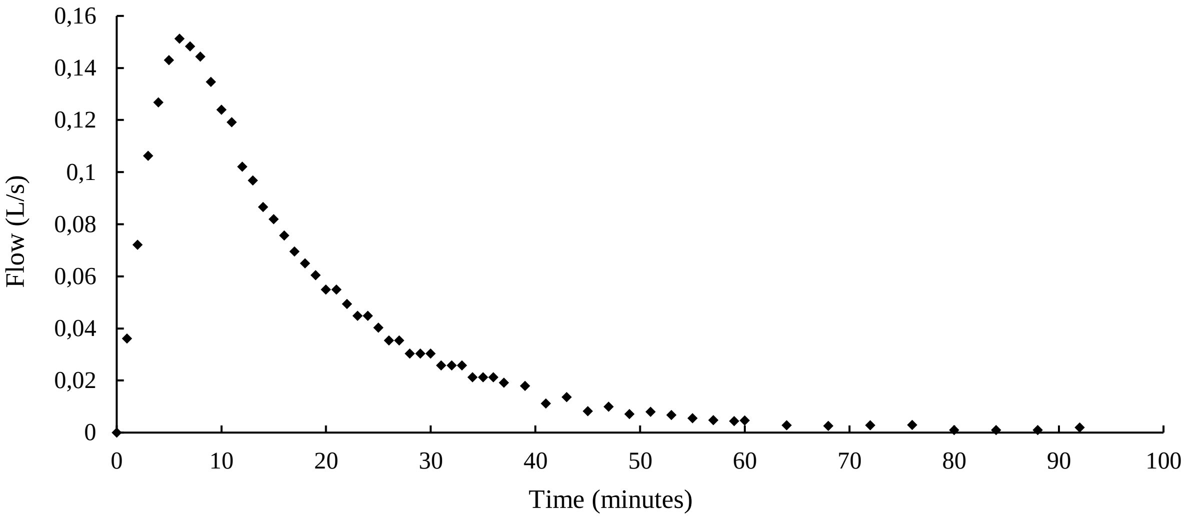
Source: Author

The formula 1 allow to approximate the volume V, knowing the water height h (cm).

$$V(L) = 0{,}0494 \times h^2 + 0{,}2458 \times h \qquad (1)$$

In this way it is possible to measure the output volume in real time, and at the same time as the oxygen measurements. Thus, knowing the volume and the oxygen concentration, it is possible to calculate an oxygen mass at the outlet (Figure 10).

Figure 10: Evolution of the flow during a pulse at the output of a VFCW-PS after calibration – 05/16/2019

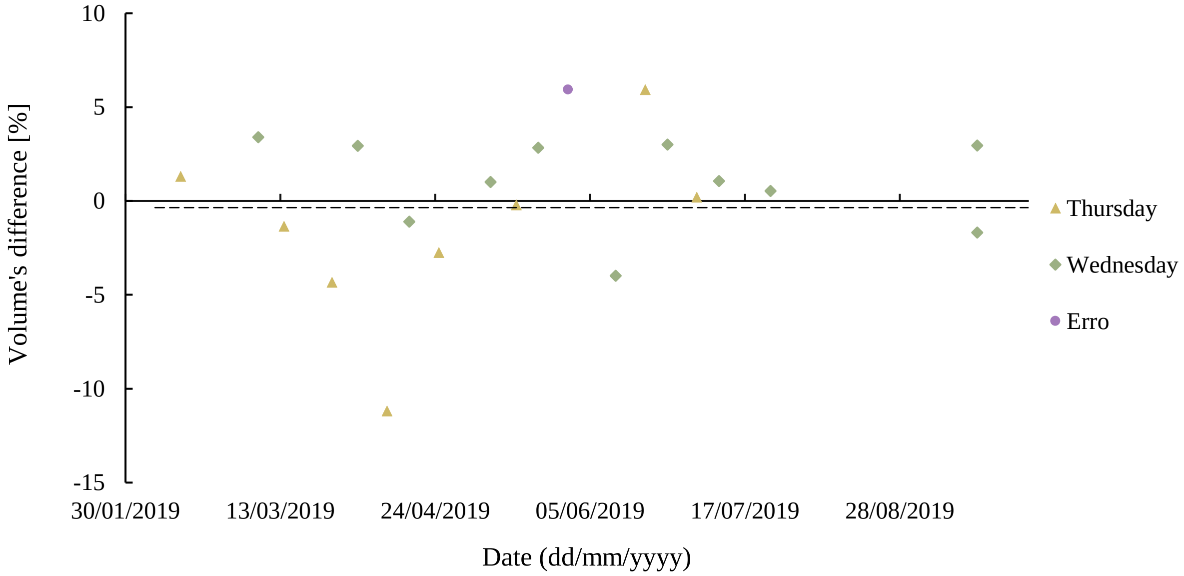


Source: Author

In order to verify if this second method of measurement is reliable, it is necessary to calculate if there is a difference and to quantify it. First it necessary to calculate the approximation error according to formula 2. To use it needs a theoretical value (counter) and an experimental measurement (ruler). The results are shown in Figure 11.

$$\delta = \frac{(V_{counter} - V_{ruler})}{V_{counter}} \times 100\% \qquad (2)$$

Figure 11: Approximation error of volumes between the two methods of measurements



Source: Author

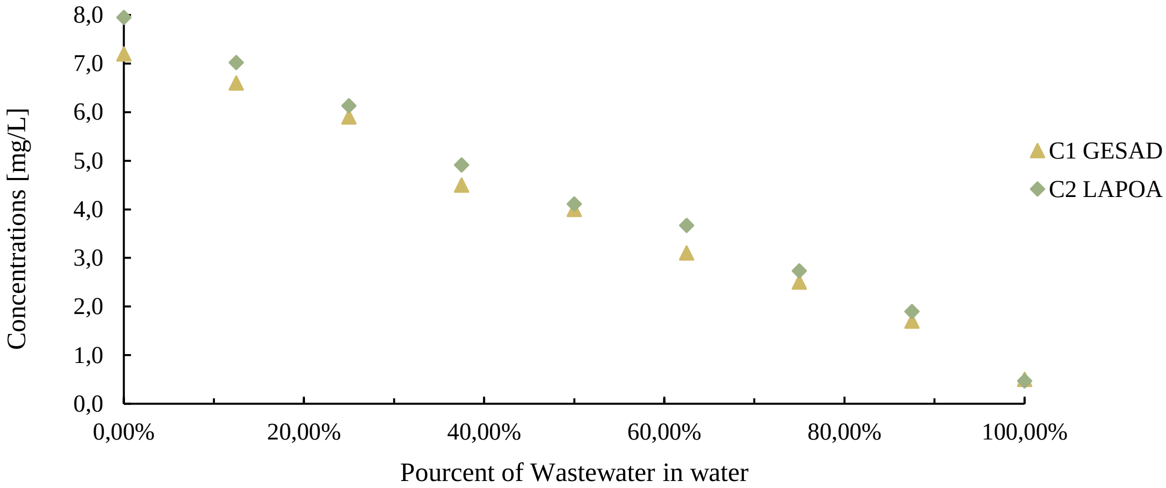
There is a slight negative error trend on Wednesdays, and a positive error on Thursdays. A probable reason is the operator difference. In fact, Wednesday's measurements are not made by the same person responsible for Thursday's measurements.

4.3.2.2 Calibration of oxygen concentration measuring instruments.

An oximeter was used to measure oxygen concentrations in the effluent. It measures the oxygen concentration in mg/L or in percentage. Concentrations appeared to be slightly elevated at first. It is for this reason that a calibration was carried out with a second oximeter, in order to validate the measurements. The GESAD oximeter has a measurement uncertainty of 0.1 mg/L while the other from the LAPOA lab is 0.01 mg/L.

Both devices were placed simultaneously in the same solutions. They are made of mixtures of tap water and wastewater at different concentrations. Each mixture has a total volume of 2L. The first measurement was made only in water. The second contains 12.5% of wastewater, the next 25% and so on until measured the oxygen concentration in wastewater only. The results are shown in Figure 12.

Figure 12: Concentrations of Oxygen in function of wastewater concentration



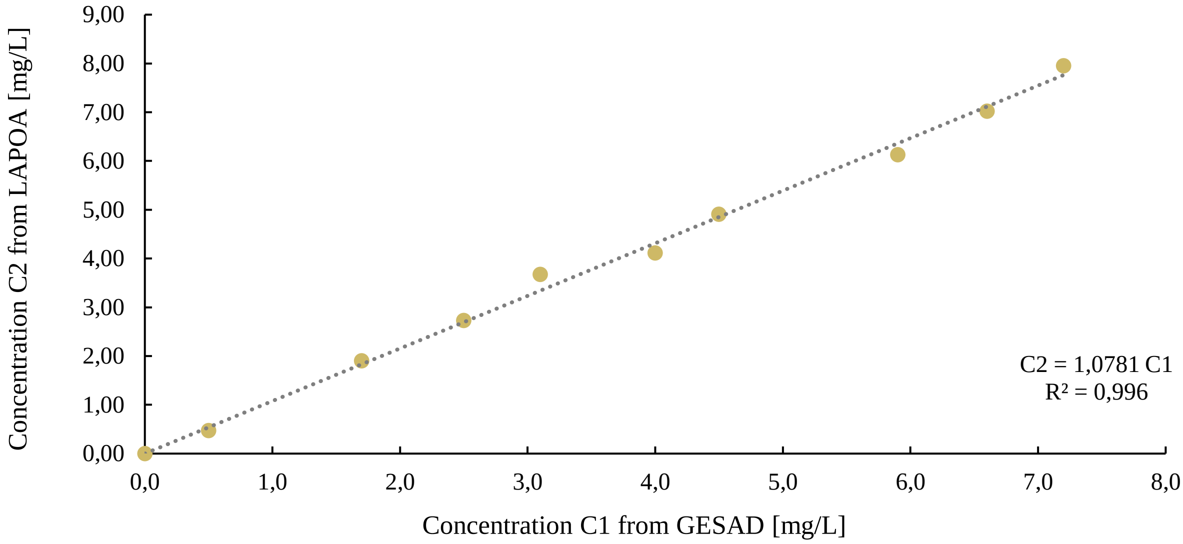
Source: Author

The concentration measurements made with the GESAD device are called C1, and the others made with the oximeter from LAPOA are called C2. The results of this calibration show that the measurements of the two oximeters are relatively similar. However, the LAPOA device did measurements consistently and slightly higher than those of GESAD.

The theory indicates that the oxygen concentration should be zero in wastewater. Measurements revealed a concentration of approximately 0.5 mg/L. When the tributary passes through the pump, to exit the CASAN network to be stored in a septic tank, the fluid can be loaded with oxygen. In addition, the weather was rainy when the collection of wastewaters was carried out. The sewers are slightly diluted. Dilution and aeration therefore explain this slight oxygen supply.

A simple report provides a calibration curve, which will correct the measurements made upstream. The graph in Figure13 gives this correction coefficient.

Figure 13: Curve made for calibration: GESAD/LAPOA



Source: Author

Below, the Formula 3 corrected the measurements of concentrations made with the GESAD oximeter. The function is linear and must pass by zero.

$$\theta_{correction} = C_2/C_1 \quad (3)$$

The result indicates that C2 measurements are 1.078 times larger than the C1. Subsequently, each measurement will be corrected by this coefficient, in order to minimize the measurement errors and thus be closer to the actual concentrations.

4.3.2.3 Mass of dissolved Oxygen

This last step of this data processing must make it possible to obtain a mass of oxygen leaving the VFCW-SB during a pulse. With the help of an oximeter it is possible to know the concentration of dissolved oxygen in real time. The oximeter is placed before the counter (Figure 14). Oxygen measurements are done at three different times. During the first half hour, they are performed each time the volume counter switches. Beyond thirty minutes, measurements are made every two minutes for a second half an hour, and every five minutes during the last half hour.

Figure 14: Pictures showing on the left (1) the location of the oximeter probe and on the right (2) the oximeter.

Source: Author

Knowing the volume leaving the system and the concentration C1 in real time it is possible to obtain a mass of oxygen according to the formulas 4 and 5. The formula 4 indicates the mass of oxygen in the case where the time is fixed. Indeed, the first half of the measurements was performed with fixed intervals of 1 minute during the first 30 min. So, each minute there are a flow *Q* (L/min) with the period of measurement *Δt* (min). It is afterwards that the concentration measurements during the first half-hour were made during the switchover, ie at fixed volume *V*. Formula 5 is used in this situation. The mass of OD is in milligram.

$$m_{OD} = Q \times \Delta t \times C_1 \times \theta_{correction} \quad (4)$$

$$M_{OD} = \sum_{ti=0}^{ti=tf} m_{OD} = \sum_{ti=0}^{ti=tf} Q_i \,.\, \Delta t_i . \bar{C}_i . \theta_{correction} \quad (5)$$

The oxygen masses are calculated for each time interval. It only remains to do a total of all these masses, form the beginning to the end of the pulse, to know the total mass. To know the average concentration of the effluent during the pulse just divide the total mass of dissolved oxygen by the total volume (Formula 6).

$$\bar{C} = M_{OD}/V_{pulse} \quad (6)$$

In this way, the first step of the data processing ends. The total volumes are known, the masses of dissolved oxygen leaving the filter and the average concentrations of each pulse too.

4.3.3 Secondary data processing (input)

To calculate the efficiency of the treatment of this filter with regard to oxygen, an input / output balance must be carried out. But to know the mass of oxygen in the input must measure the mass of oxygen consumed. For this we use the Formula 7, which follows directly from the research of Platzer in 1999.

$$m_{OD} = (0{,}7\ \Delta COD + 4{,}3\ \Delta TKN - 2{,}86\ \Delta TN) \times V_{tot} \tag{7}$$

Every two weeks, a GESAD team carries out wastewater collection upstream of the filter (input) and after treatment (output). Various manipulations are then carried out in order to know the concentrations of several components and parameters. Those needed for this study are COD and Nitrogen because the formula 7 is using COD, TKN and TN.

4.3.3.1 Laboratory analysis

The collected samples were put in plastic bottles and the analyzes were performed directly after, on the same day of the collections every two weeks. The parameters analyzed are described in Table 3 and followed the recommendations of the Standard Methods for the Examination of Water and Wastewater, APHA (1998), APHA (2005), and Vogel (1981). (NUNES DE FREITAS, 2017)

Table 3: Methods for measuring chemical parameters.

Parameters	*Methodology used*	*Units*
pH	Direct, Potentiometric (APHA, 2005)	-
COD	COD Closed reflux digestion (APHA, 2005)	mg/L
BOD	BOD Manometric Method (APHA, 2005)	mg/L
N-NH4⁺	Nessler Method (VOGEL, 1981)	mg/L
N-NO2¯	Alphantylamine Method (APHA, 1998)	mg/L
N-NO3¯	Alphantylamine Method (APHA, 1998)	mg/L
TN	Colorimetric Method - Persulfate Digestion – kit Hach® (APHA, 2005)	mg/L

Source: Inspirated by (NUNES DE FREITAS, 2017)

4.3.3.2 Calculation of the mass of oxygen consumed

The measurements made in the laboratory give results in the form of concentrations influent and effluent of the treatment. It is necessary to convert these data into mass variation; annotated dm. Divide the difference in concentration (mg / L) by volume (L) to obtain the dm in mg (formula 9 & 10).

$$dm_{COD} = ([COD_{input}] - [COD_{output}]).V_{pulse} \quad (9)$$

$$dm_{TN} = ([TN_{input}] - [TN_{output}]).V_{pulse} \quad (10)$$

To know the mass of NTK is a more complex. Subtract the mass of nitrite and nitrate from the total nitrogen mass. Formulas 11, 12, 13, 14 and 15 show the relationship between the different forms under which Nitrogen is present (PÜTZ, 2018).

$$TN = N_{org} + N_{NH4} + N_{NO2} + N_{NO3} \quad (11)$$

$$TKN = N_{org} + N_{NH4} \quad (12)$$

$$dm_{N_{NO_2}} = \left(\left[N_{NO2_{input}}\right] - \left[N_{NO2_{output}}\right]\right).V_{pulse} \quad (13)$$

$$dm_{N_{NO_3}} = \left(\left[N_{NO3_{input}}\right] - \left[N_{NO3_{output}}\right]\right).V_{pulse} \quad (14)$$

$$dm_{TKN} = dm_{TN} - dm_{N_{NO_2}} - dm_{N_{NO_3}} \quad (15)$$

All that is done upstream now makes it possible to calculate the mass of oxygen consumed in vertical filter.

4.3.4 Wastewater treatment performance

A final step remains to determine the efficiency of the treatment in terms of oxygen removal and flow. Knowing the masses of oxygen at the outlet of the filter and the oxygen consumed, it is necessary to calculate the mass of oxygen at the inlet to make the balance: Input/Output. Formulas 16 and 17 present the final calculations made in this work.

$$M_{DO.input} = M_{DO.consumed} + M_{DO.output} \quad (16)$$

$$ef = M_{DO.input} - M_{DO.output} \Big/ M_{DO.intput} \qquad (17)$$

The flow of oxygen *j* depends on the surface *A* of the filter (m^2) and oxygen mass that enters the filter, $M_{DO.input}$. The formula 18 makes it possible to calculate the flow of oxygen in $g.m^{-2}$. To know the average flow of oxygen during a pulse must take into account the pulse duration of 3 hours, called t_{pulse}. The formula 19 show it in $g.m^{-2}.h^{-1}$.

$$j_{pulse} = \frac{M_{DO.input}}{A} \qquad (18)$$

$$\overline{J_{pulse}} = \frac{M_{DO.input}}{A\,.t_{pulse}} \qquad (19)$$

The number of pulses, n_{pulse}, is fixed by Table 2. The average oxygen flux per day corresponds to the flow of oxygen during a pulse multiplied by the number of pulse ($n_{pulse} = 3$ on Monday and Thursday, and 4 on Tuesday and Wednesday). The formula 20 introduce it in $g.m^{-2}.d^{-1}$.

$$j_{daily} = \frac{M_{DO.input}}{A} \times n_{pulse} \qquad (20)$$

It is interesting to calculate the charge removed from COD, NH_4^+ and TN. The charge removed is called *CR* and is in $kg.L.m^{-2}.h^{-1}$. Formulas 21, 22 and 23 respectively show how to obtain these results. The mass variations are in *kg*, volumes are in *L*, the area A is in m^2 and the duration of the pulse, t_{pulse}, is 3h.

$$CR_{COD} = \frac{\Delta M_{COD} \times V_{pulse}}{A \times t_{pulse}} \qquad (21)$$

$$CR_{NH_4^+} = \frac{\Delta M_{NH_4^+} \times V_{pulse}}{A \times t_{pulse}} \qquad (22)$$

$$CR_{TN} = \frac{\Delta M_{TN} \times V_{pulse}}{A \times t_{pulse}} \qquad (23)$$

It is also possible to calculate the elimination efficiency of these three elements. The elimination efficiencies are express in percentage, and are called ef_e. A simple ratio between the concentrations (*mg/L*) of the tributary and the effluent gives this result. Formulas 24, 25 and 26 indicate how to obtain these results respectively for DOC, NH_4^+ and TN.

$$ef_{e-COD} = \left(1 - \frac{C_{COD-output}}{C_{COD-input}}\right) \times 100 \tag{24}$$

$$ef_{e-NH_4^+} = \left(1 - \frac{C_{NH_4^+-output}}{C_{NH_4^+-input}}\right) \times 100 \tag{25}$$

$$ef_{e-TN} = \left(1 - \frac{C_{TN-output}}{C_{TN-input}}\right) \times 100 \tag{26}$$

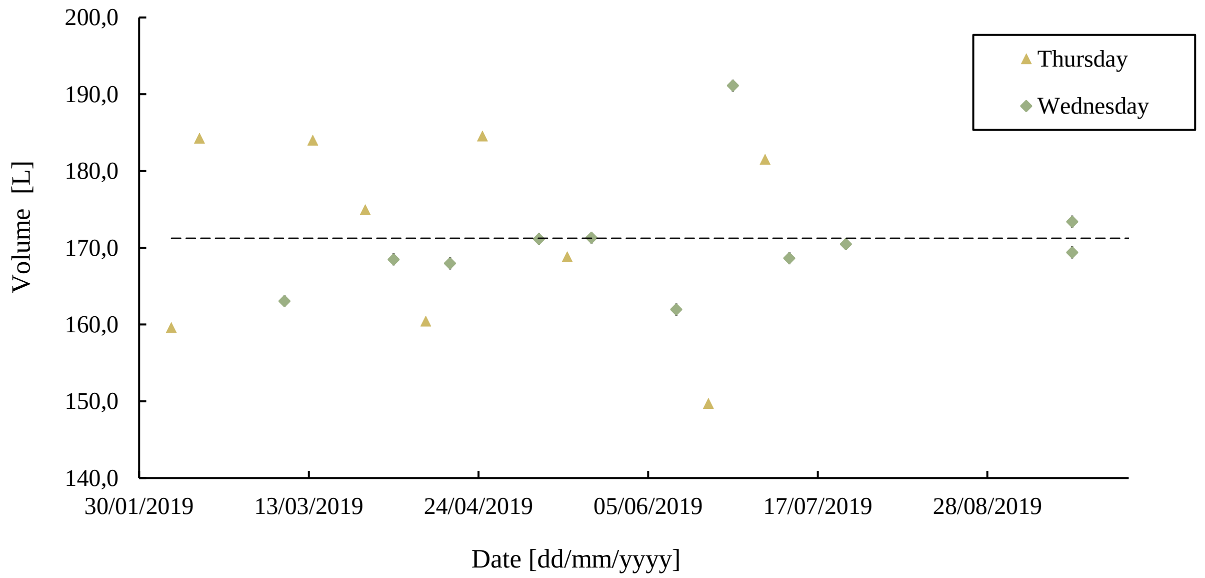
5 RESULTS

5.1 Primary data processing

5.1.1 Volume and Flow Calculations

The 21 measurements make it possible to obtain an average volume per pulse of 171.2 L. The minimum volume was recorded on 20/06/2019 with 149.7 L while the maximum is reached on 30/05/2019 with 285, 6 L. This point won't be used because of the difference with the others points. This day rained a lot. The graph in Figure 15 shows the volumes measured by the scale counter, with a vertical bar symbolizing the volume difference between the two methods presented previously. The horizontal lines represent the average and the 95% confidence interval in red.

Figure 15: Volume of treated wastewater measured at the outlet of the VFCW-PS filter



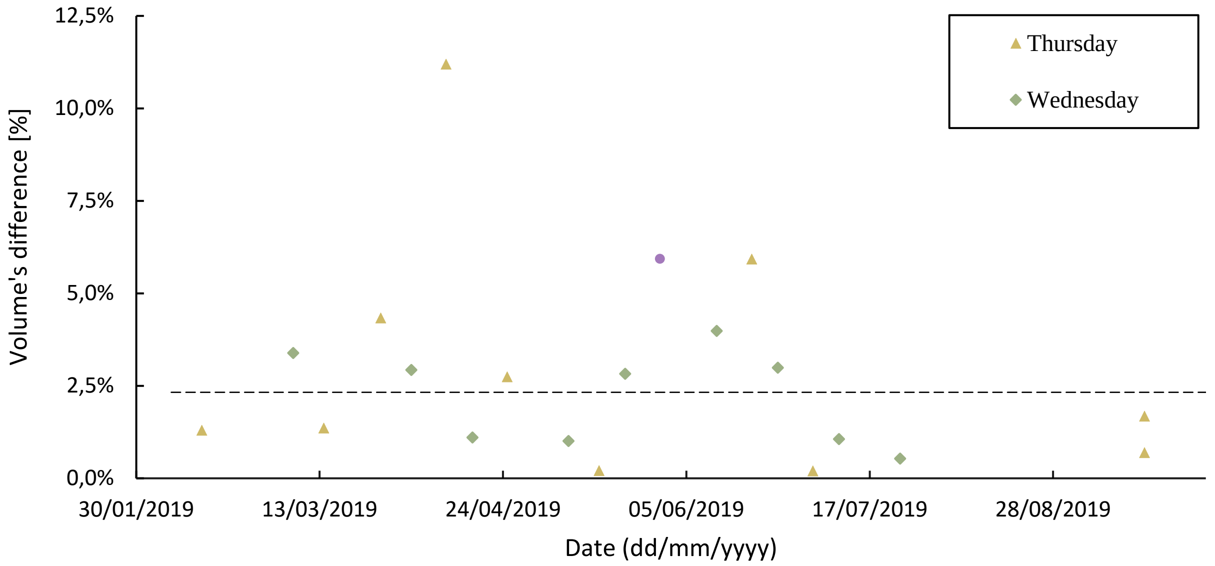
Source: Author

The standard deviation is 10.09. It indicates that the measures are flickering around the average. Indeed, 95% of the values are in a range of 40 L.

Weather conditions are responsible for variations. The measurement during a drier period will give a smaller output volume due to the evapotranspiration a higher absorption by the filter medium and the macrophytes. Otherwise, as was the case on 30/05/2019 during a rainy season, the output volume can be up to twice as high.

The volume approximation method generates an error. This is given in the graph of Figure 11, but below there are the same with absolute values (Figure 16). The average error in absolute values is 2.4%, the standard deviation is 0.02%. The IC 95% indicate that 95% of absolutes values will have an error between 0% and 7,72%

Figure 16: Approximation error in absolute of volumes in between the two methods of measurements



Source: Author

In order to calculate the average of these deviations, absolute values are required. Thus, the Table 4 show the min and max values, the average and other statistics.

Table 4: Statistics about the calibration of volume measurement instruments

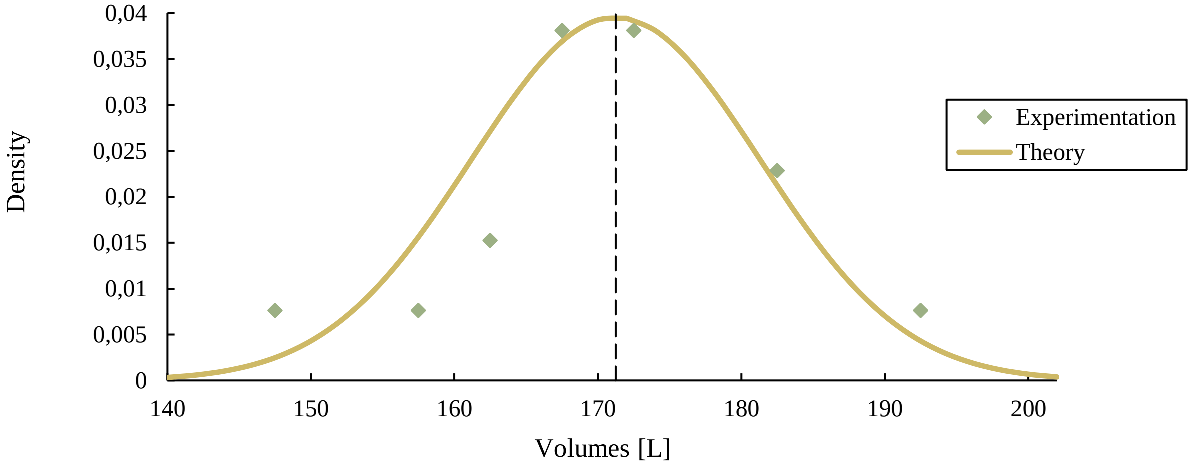
	Counter [L]	***Ruler [L]***	***Difference [L]***	***Approximation Error [%]***
Minimum	149,7	149,4	0,3	0,2%
Maximum	285,6	268,7	18,0	11,2%
Average	171,2	172,4	4,2	2,4%
Standard deviation	10,09	10,32	4,00	0,02
IC 95%	19,77	20,23	7,83	0,05

Source: Author

Measurement errors related to instruments are negligible with respect to the influence of the weather. This is why the volume approximation method is validated and used later.

The average volume difference is 2.4%, indicating that the measures appear reliable. IC 95 asserts that in 95% of cases, there will be a difference of less than / or equal to 5% between the two volume measurement methods. The maximum difference is referenced to April 11, 2019, and the minimum to June 26. The use of the certainty index (IC 95%) is used only because the number of values is sufficient (21 values) and because the distribution follows the law of probability called: normal distribution (Figure 17). This normal law is centered around the average which is 171.2 L.

Figure 17: Normal distribution of volumes (Law of probability)



Source: Author

The measurements were performed on Wednesday morning (first pulse) and Thursday afternoon (Third pulse). There is therefore a big difference in terms of experimental condition. The filter can rest longer before the first pulse (15h) than between two pulses (1:30). To better understand the difference, we use the Table 5 and the Figure 18. The statistical results in Table 4 are modified according to the day of collection.

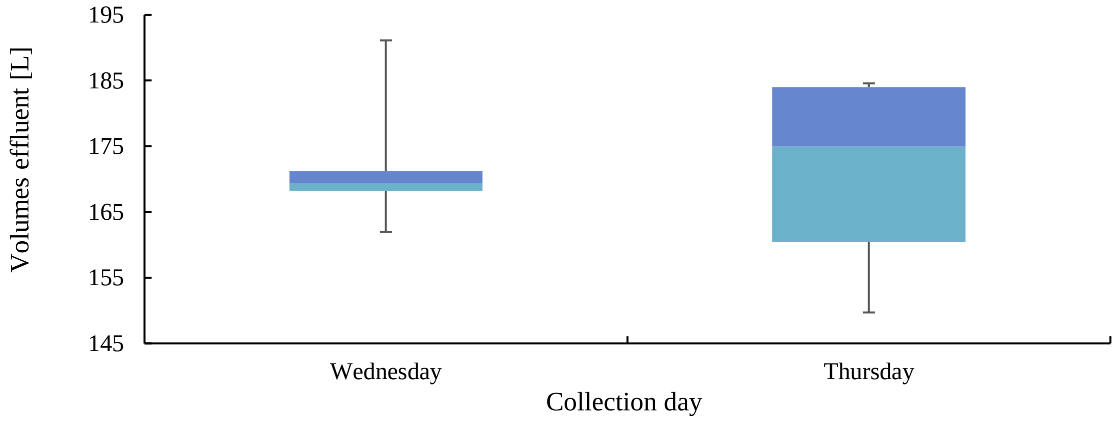
Table 5: Volumes statistics to compare the collection day

	Wednesday [L]	***Thursday [L]***
Minimum	161,9	149,7
Maximum	191,1	184,6
Average	170,6	172,0
Standard Deviation	7,6	12,9

Source: Author

The results seem to be relatively similar Wednesday and Thursday by reading the Table 5. The graph of Figure 18 makes it possible to better take into account the distribution of the data.

Figure 18: Volumes statistics to compare the collection day



Source: Author

The gaps between the smallest and the largest value are equal. The averages are closed with 1.4 L difference. But the variations of volumes are more important on Thursdays. The filter is not powered at night, so he cans rest. This allows him to be drier during the first pulse. Under these conditions the infiltration rate is faster and there is more absorption. This is not the case on Thursdays because it is the third pulse of the day, and the filter could only rest for 90 minutes.

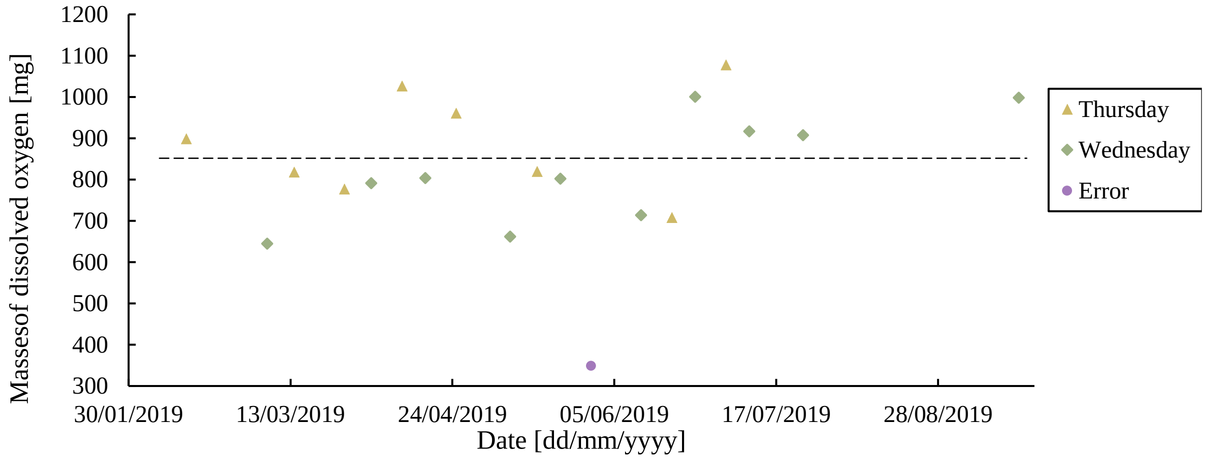
5.1.2 Masses Calculations

Oxygen concentration measurements were performed at the same time as the volumes. The measuring instrument is an oximeter digital of the brand Instrutherm®. It measures with a possible error of the order of a tenth. That is between 1% error, with high concentration, and 5,5% error with low concentrations.

From formulas 4 and 5, the concentrations were multiplied by volume. Thus, is obtained masses per time interval. The masses have been corrected according to formula 3, which is the calibration formula of the measuring device. The sum of these corrected masses gives a total mass of oxygen leaving the filter in 90 min, ie during a pulse.

The results are shown in Figure 19 below. Wednesdays' measures are differentiated from those of Thursdays. Wednesday is the pulse of 8 a.m, the first of the day after a period of rest of 15h. The pulses of Thursdays are at 2 p.m, the third pulse of the day, after a break of 1h30. The horizontal lines are the average (in black) and the 95% confidence interval (in red).

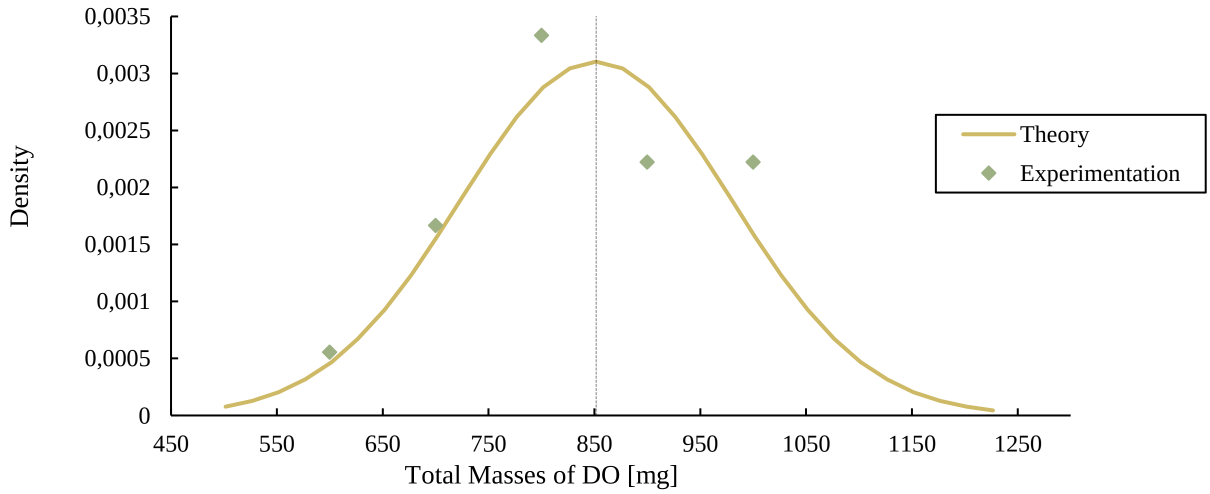
Figure 19: Total mass of dissolved oxygen per pulse



Source: Author

In the same way as for the results of the volumes, it is necessary to check that the distribution of the results of the masses follows the normal distribution. Thus, the uncertainty index IC 95% can be used. We consider that is following the normal distribution.

Figure 20: Normal distribution of DO masses (Law of probability)



Source: Author

Table 6 below shows the statistical values. The average mass leaving the vertical filter saturated bottom is 851,69 mg. The 95% confidence interval (95% CI) is plus or minus 251,95 mg. This beach is large but a multitude of bills come into play. There is the error on volumes, weather conditions too. For example, the day he liked the most, the outgoing volume being twice as high. It was the 30/05/2019. That is less than half of the average oxygen mass. Added to this is the 1-5 % uncertainty of the concentration measuring instrument. It is noted that the variations are mainly related to weather conditions.

Table 6: Statistics values about masses measurement before and after the calibration.

	Mass M measured [mg]	***Mass M corrected [mg]***
Minimum	323,7	349,0
Maximum	999,7	1077,8
Average x	789,9	851,7
Standard deviation d	117,08	128,6
d/x	14,90%	14,90%
IC 95%	233,70	251,95

Source: Author

To better understand the difference, we use the Table 7 and the Figure 21. The statistical results in Table 6 are modified according to the day of collection. The point of the rainy day (30/05/2019) is not take into account.

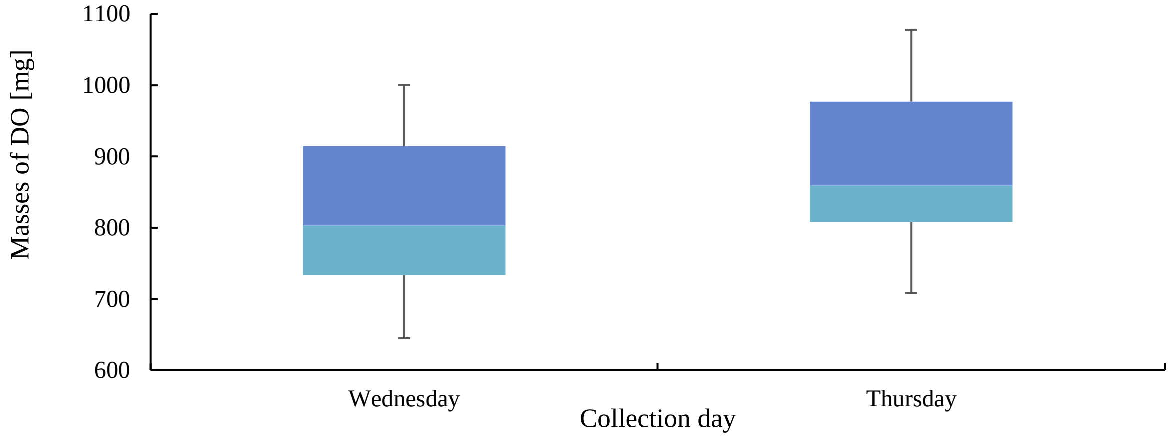
Table 7: Masses of DO statistics to compare the collection day

	Wednesday [mg]	***Thursday [mg]***
Minimum	644,9	708,5
Maximum	1000,3	1077,8
Average	824,2	885,9
Standard Deviation	119,5	118,7

Source: Author

The results seem to be relatively similar Wednesday and Thursday by reading the Table 7. The graph of Figure 21 makes it possible to better take into account the distribution of the data.

Figure 21: OD masses statistics to compare the collection day



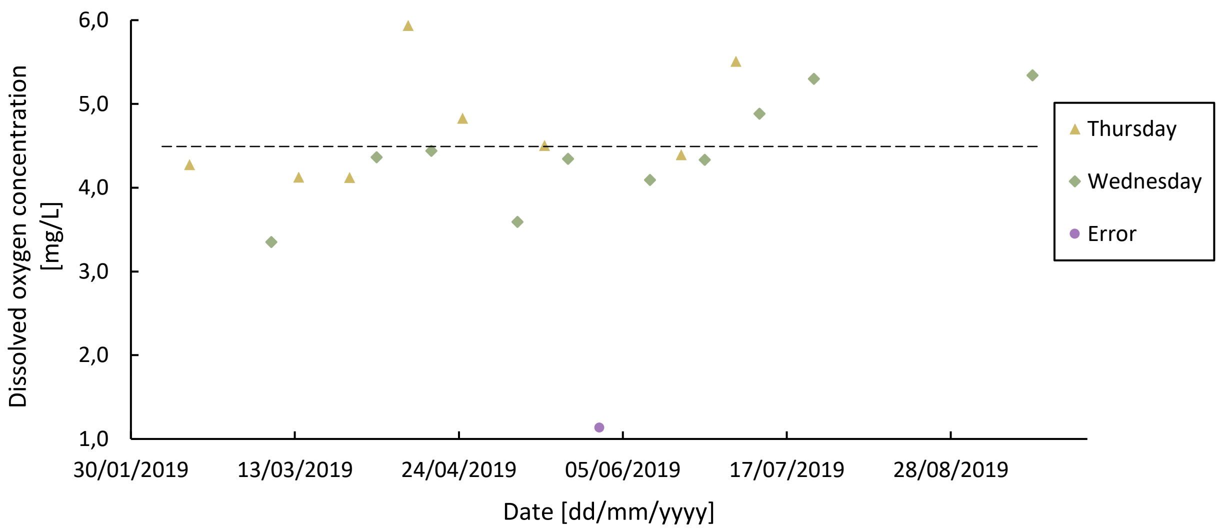
Source: Author

The graph in Figure 21 confirms the hypothesis that the distribution of results is similar on Wednesdays and Thursdays. The gaps between the smallest and the largest value are almost equal. The averages are closed with 61.7 mg difference.

5.1.3 Calculations of Concentrations

To know the average concentration of dissolved oxygen in the effluent the mass is divided by the volume (Formula 6). The results are shown in Figure 22. On average, there is 4.49 mg/L of dissolved oxygen. The 95% confidence interval is plus or minus 1.29 mg/L.

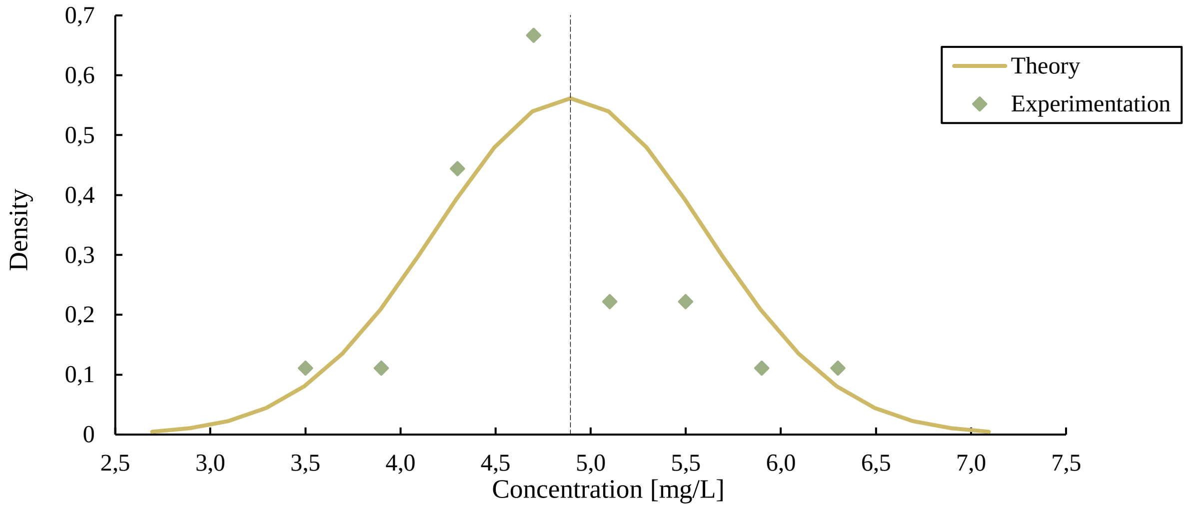
Figure 22: Dissolved oxygen concentration per pulse



Source: Author

In the same way as for the results of the volumes and masses of OD, it is necessary to check that the distribution of the results of the average concentration of OD follows the normal distribution. Thus, the uncertainty index IC 95% can be used. We consider that is following the normal distribution.

Figure 23: Normal distribution of average concentration of DO (Law of probability)



Source: Author

The statistics results are shown in the summary Table 8 below. All the measures used to calculate these statistical values are presented in the Annex A.

Table 8: Statistics values from the first data processing

	Volume V [L]	***Mass M [mg]***	***Concentration C [mg/L]***
Minimum	149,7	349,0	1,22
Maximum	285,6	1077,8	6,4
Average x	172,56	846,9	4,89
Standard deviation d	11,17	126,2	0,71
d/x	6,48%	14,90%	14,52%
IC 95%	21,9	247,4	1,39

Source: Author

The masses are between 4 and 5 times higher than the volumes. The d/x ratio indicates that this series of mass data varies more (14.90%) than volumes (6.48%). The concentration follows the trend of the masses.

To better understand the difference, we use the Table 9 and the Figure 24. The statistical results in Table 8 are modified according to the day of collection. The point of the rainy day (30/05/2019) is not take into account.

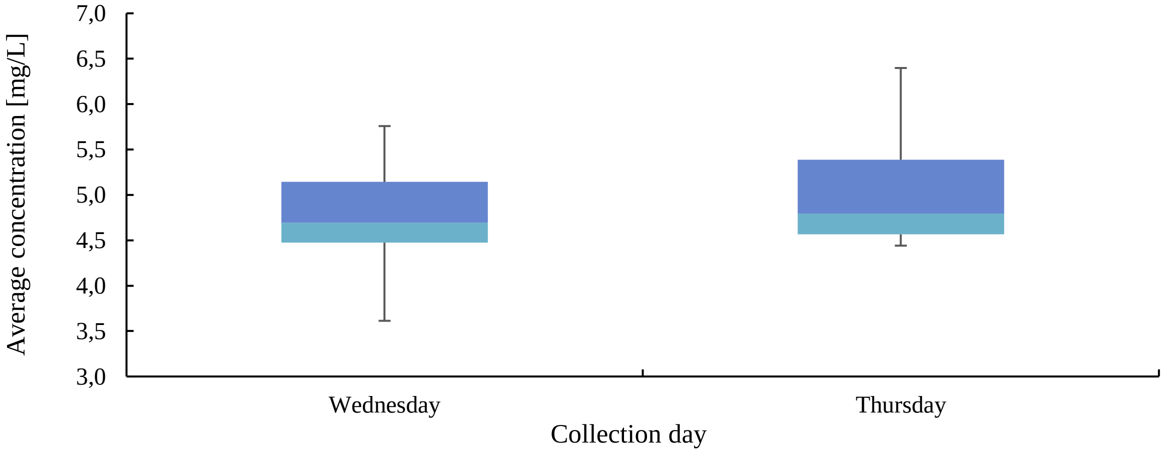
Table 9: Average concentrations of DO statistics to compare the collection day

	Wednesday [mg/L]	***Thursday [mg/L]***
Minimum	644,9	708,5
Maximum	1000,3	1077,8
Average	824,2	885,9
Standard Deviation	119,5	118,7

Source: Author

The results seem to be relatively similar Wednesday and Thursday by reading the Table 9. The graph of Figure 24 makes it possible to better take into account the distribution of the data.

Figure 24: Average concentrations of DO statistics to compare the collection day



Source: Author

The graph in Figure 24 confirms the hypothesis that the distribution of results is similar on Wednesdays and Thursdays. The gaps between the smallest and the largest value are almost equal. The averages are closed with 0,33 mg/L difference.

5.2 Secondary data processing

The second data processing uses the values obtained so far and the measurements made by other GESAD members. There are four steps that are distinguished by the following subtitles.

5.2.1 Oxygen output

The quantity of oxygen leaving the filter is already known thanks to the first data processing. Of the 19 measurements taken before, only 9 are used now. Indeed, it is necessary to cross the data. The measurements making it possible to calculate the mass of oxygen consumed in the filter are generally carried out every two weeks; twice as often as the measurements of the first data processing. Table 10 below shows the measures selected for this second data processing.

Table 10: Masses of DO from selected samples from the first data processing

Date [dd/mm/yyyy]	***n° sample***	***Masses DO [mg]***
07/03/2019	84	644,88
03/04/2019	86	792,22
17/04/2019	87	803,80
09/05/2019	88	662,32
22/05/2019	89	802,32
12/06/2019	90	714,22
26/06/2019	91	928,51
10/07/2019	92	887,30
24/07/2019	93	973,90

Source: Author

The study period is therefore reduced between 07/03/2019 and 24/07/2019, which is about 2 months less.

5.2.2 Oxygen consumed in the filter

Two samples are collected during this step. The first upstream of the filter comes from the tank of equalization, and the second downstream of the filter comes from the counter of flip-flops. In the GESAD laboratory it is possible to measure the concentrations of COD, Total Nitrate, Ammonium, Nitrite and Nitrate following the methods showed in the Table 3. The formulas 9 10 and 15 make it possible to calculate the variations of masses *dm* of these elements. The results are shown in Table 11 (COD) and Table 15 (Other Chemical Elements) below.

Table 11: Masses of COD consumed (*dm*) in the VFWC-PS filter

Date [dd/mm/yyyy]	*COD Affluent [mg L^{-1}]*	*COD Effluent [mg L^{-1}]*	*COD_Remotion [%]*	*Volume [L]*	*dm (COD) [g]*
07/03/2019	291,34	11,09	96,20	163,07	45,70
20/03/2019	368,01	13,14	96,43	165,55	58,75
03/04/2019	515,44	19,68	96,18	168,49	83,53
17/04/2019	401,91	17,23	95,71	167,96	64,61
09/05/2019	380,33	31,07	91,83	171,14	59,77
22/05/2019	426,13	12,11	97,16	171,30	70,92
12/06/2019	524,07	39,20	92,52	161,95	78,52
26/06/2019	39,89	22,74	42,99	191,11	3,28
10/07/2019	961,72	29,10	96,97	168,63	157,27
24/07/2019	400,97	25,85	93,55	170,48	63,95

Source: Author

There were 10 measurement campaigns between March and July 2019. On the 26/06/2019, the COD measurement is very low and is therefore not taken into account later. On the 10/07/2019, the measure of COD is this time too high. There was a high rate of solids and COD due to the pump rotor change upstream of the septic tank. This measure is therefore not taken into account. It remains then 8 reliable measurements.

In the Table 12 the statistical results are given from the 8 measurement campaigns selected.

Table 12: Statistics values about the COD consumed in the VFWC-PS

	COD Affluent [mg L^{-1}]	*COD Effluent [mg L^{-1}]*	*Volume [L]*	*dm (COD) [g]*
Min	291,34	11,09	161,95	45,70
Max	524,07	39,20	171,30	83,53
Average x	413,52	21,17	167,49	65,72
Standart deviation d	76,68	10,08	3,62	11,94
d/x	18,5%	47,6%	2,2%	18,2%

Source: Author

The quotient d/x, indicating the relative variation, shows that the concentration of DOC at the outlet of the filter varies greatly (47.6%). The volume, on the other hand, is almost constant with a ratio of 2.2%. These two variables give the mass variation *dm* with an average of 65.72 g.

According to the formulas 10 and 15 it is possible to obtain the mass variations of TKN and TN. It should be noted that TN measurements are performed once a month. This has an effect on the number of useful data. The table 13 gives the data used to calculate TN and TKN.

Table 13: Concentration of chemical elements measured to calculate TN and TKN

	Affluent				***Effluent***			
Date	**TN**	**N-NH_4^+**	**N-NO_2^-**	**N-NO_3^-**	**TN**	**N-NH_4^+**	**N-NO_2^-**	**N-NO_3^-**
	mg L^{-1}	*mg L^{-1}*	*mg L^{-1}*	*mg L^{-1}*	*mg L^{-1}*	*mg L^{-1}*	*mg L^{-1}*	*mg L^{-1}*
07/03/2019	~~38,00~~	43,50	0,10	3,50	~~3,00~~	4,50	0,01	22,90
20/03/2019	-	54,00	0,13	-	-	7,50	0,00	-
03/04/2019	86,00	70,50	0,14	1,05	33,00	11,00	0,00	11,65
17/04/2019	-	71,00	0,13	1,20	-	14,50	0,05	24,00
09/05/2019	-	70,50	0,13	1,45	-	13,75	0,01	18,30
22/05/2019	66,00	66,50	0,15	1,10	28,00	17,50	0,00	21,15
12/06/2019	-	37,40	0,10	1,80	-	3,97	0,65	20,60
26/06/2019	65,00	31,45	0,11	0,55	52,00	5,13	0,02	33,35
10/07/2019	-	39,05	0,08	1,50	-	8,35	0,03	28,85
24/07/2019	~~29,00~~	35,45	0,16	1,15	27,00	10,70	0,01	24,50

Source: Following the GESAD's work

Ammonium, nitrate and nitrite concentrations make it possible to calculate the mass variation of TKN according to formulas 11, 12, 13 and 14. The results of TN and TKN are presented in Table 14. TN concentrations are lower than N-NH4 concentration the 07/03/2019.

Table 14: Masses variations of NTK and TN consumed (*dm*) in the VFWC-PS filter

Data	***dm NTK***	***dm NT***
	[g]	[g]
07/03/2019	8,86	5,7
03/04/2019	10,69	8,9
22/05/2019	9,92	6,5
26/06/2019	8,74	2,5
24/07/2019	4,30	0,34

Source: Following the GESAD's work

The mass variations *dm* of total nitrogen (TN) and total Kjeldahl nitrogen (TKN) are big. This is mainly due to the measure of 24/07/2019 which is very low. There are only 5 TN measurement campaigns. This reduces the amount of useful data afterwards. Following the Statistics values about the mass variations of TKN and TN in the table 15.

Table 15: Statistics values about the mass variations of TKN and TN

	dm TKN [g]	***dm TN [g]***
Min	4,30	0,34
Max	10,69	8,93
Average x	8,50	4,79
Standard deviation d	2,48	3,39
d/x	29,2%	70,8%

Source: Following the GESAD's work

Finally, knowing the mass variations of COD, TN and TKN, it is possible to calculate the mass of oxygen consumed in the filter according to formula 6 (Table 16).

Table 16: Summary Table showing dissolved oxygen masses consumed in the VFWC-PS

Date [dd/mm/yyyy]	***dm COD [g]***	***dm NTK [g]***	***dm NT [g]***	***m (DO) [g]***
07/03/2019	45,70	8,86	5,7	53,75
20/03/2019	58,75	-	-	-
03/04/2019	83,53	10,69	8,9	78,91
17/04/2019	64,61	-	-	-
09/05/2019	59,77	-	-	-
22/05/2019	70,92	9,92	6,5	73,68
12/06/2019	78,52	-	-	-
26/06/2019	3,28	8,74	2,5	32,75
10/07/2019	157,27	-	-	-
24/07/2019	63,95	4,30	0,3	62,26

Source: Author

Of the initial 10 samples, there remains a series of oxygen mass data consumed m_{OD} consisting of only 4 data. The measurements taken on 26/06/2019 are not taken into account because of the low concentration of COD in the tributary.

The average of dissolved oxygen mass consumed is 67.15 g. The standard deviation is 11.32, which gives a d/x ratio of 16.9%. The variation is quite high, because greater than 10% (Table 17).

5.2.3 Oxygen input and wastewater treatment performance

From formula 16 it is possible to calculate the amount of oxygen that enters the filter from the previous data. Indeed, what enters is equal to the sum of what is consumed and what comes out of the filter (Table 17).

The efficiency *ef* is calculated from the masses of oxygen that enters and exits. Formula 17 shows how the last column is obtained.

Table 17: Summary Table about consummation and flows of dissolved oxygen, and efficiency of the VFWC-PS

Date [dd/mm/yyyy]	***N° sample -***	***m DO consumed [g]***	***m DO output [g]***	***m DO input [g]***	***Ef %***
	Minimum	53,75	0,644	54,40	98,56%
	Maximum	78,91	0,907	79,70	99,01%
	Average x	67,15	0,786	67,94	98,83%
	Standard variation d	11,32	0,108	11,36	0,19%
	d/x	16,9%	13,7%	16,7%	0,19%
07/03/2018	84	53,75	0,645	54,40	98,81%
03/04/2019	86	78,91	0,791	79,70	99,01%
22/05/2019	89	73,68	0,802	74,48	98,92%
24/07/2019	93	62,26	0,908	63,17	98,56%

Source: Author

The results in the Table 17 indicate that oxygen entering the filter is 98.83% consumed. The VFWC-PS therefore has a high capacity to consume oxygen from exchanges with the atmosphere and the effluent.

Formulas 21, 22 and 23 are used to calculate the charge removed of COD, NH_4^+ and TN. The COD mass variations and pulse volumes are shown in Table 11, and the concentrations used to calculate NH_4^+ and TN mass changes are shown in Table 13. The CR are shown in Table 18.

The results in the Table 18 indicate that the filter has the ability to reduce the charge of COD an average of 0.576 $kg.L.m^{-2}.h^{-1}$, the charge of NH_4^+ of 58.0 $g.L.m^{-2}.h^{-1}$ and the change of TN of 52.6 $g.L.m^{-2}.h^{-1}$. The ability to reduce the COD load is much higher but does not mean better, because the COD concentrations are much higher too (Table 11 and 13).

Table 18: Charge removed of COD, NH_4^+ and TN in the VFCW-PS

Date	***CR-COD*** *$g.L.m^{-2}.h^{-1}$*	***CR-NH_4^+*** *$g.L.m^{-2}.h^{-1}$*	***CR-NT*** *$g.L.m^{-2}.h^{-1}$*
Minimum	27,8	32,0	2,6
Maximum	1178,7	75,1	66,9
Average	512,2	53,9	36,3
Standard deviation	286,6	16,2	25,0
07/03/2019	331,23	46,1	41,4
20/03/2019	432,26	56,6	
03/04/2019	625,54	75,1	66,9
17/04/2019	482,34	70,8	
09/05/2019	454,62	73,9	
22/05/2019	539,94	63,9	49,6
12/06/2019	565,19	39,0	
26/06/2019	27,84	42,7	21,1
10/07/2019	1178,70	38,8	
24/07/2019	484,51	32,0	2,6

Source: Author

The elimination efficiencies of these three same elements are calculated from formulas 24, 25 and 26. The results are given in Table 19.

Table 19: Efficiencies of elimination of COD, NH_4^+ and TN in the VFCW-PS

Date	***$ef_{e\text{-}COD}$*** ***%***	***$ef_{e\text{-}NH4+}$*** ***%***	***$ef_{e\text{-}NT}$*** ***%***
Minimum	43,0%	69,8%	6,9%
Maximum	97,2%	89,7%	92,1%
Average	88,6%	83,4%	57,8%
Standard deviation	0,185	0,054	0,296
07/03/2019	96,2%	89,7%	92,1%
20/03/2019	96,4%	86,1%	
03/04/2019	96,2%	84,4%	61,6%
17/04/2019	95,7%	79,6%	
09/05/2019	91,8%	80,5%	
22/05/2019	97,2%	73,7%	57,6%
12/06/2019	92,5%	89,4%	
26/06/2019	43,0%	83,7%	20,0%
10/07/2019	97,0%	78,6%	
24/07/2019	93,6%	69,8%	6,9%

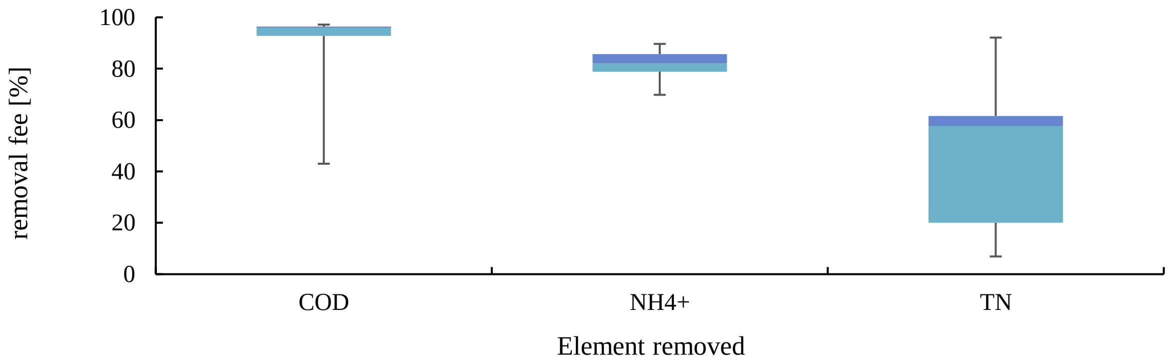
Source: Author

The efficiency of the filter to reduce the COD is high with 88.6% of Average and with very small variations (Standard deviation: 0.18). The same is true for the elimination of Ammonium and TN with 83.4% and 57.8% respectively.

Identical measurements have been performed previously on the same VFCW-PS filter by the GESAD. The reduction of COD was evaluated at 91%, ammonium at 66% and TN at 45% (SEZERINO et al., 2018).

The efficiency to reduce the COD is lower because of the measurement of 26/06/2019. Otherwise the average would be higher than that presented by the GESAD with 92.5% of removal fee. On the contrary, the elimination of Ammonium and total nitrate is greater with the measurements of 2019. And this is valid despite a low removal fee of TN on 24/07/2019. It is noted that the variations in efficiency are relatively low for NH_4^+. Between 07/03/2019 and 24/07/2019 the effectiveness of the filter to eliminate TN has steadily decreased, ranging from 92.1% to 6.9%.

Figure 25: Efficiency of VFCW-PS filter to removed COD, NH_4^+ and TN (2019)



Source: Author

5.2.4 Oxygen exchanges

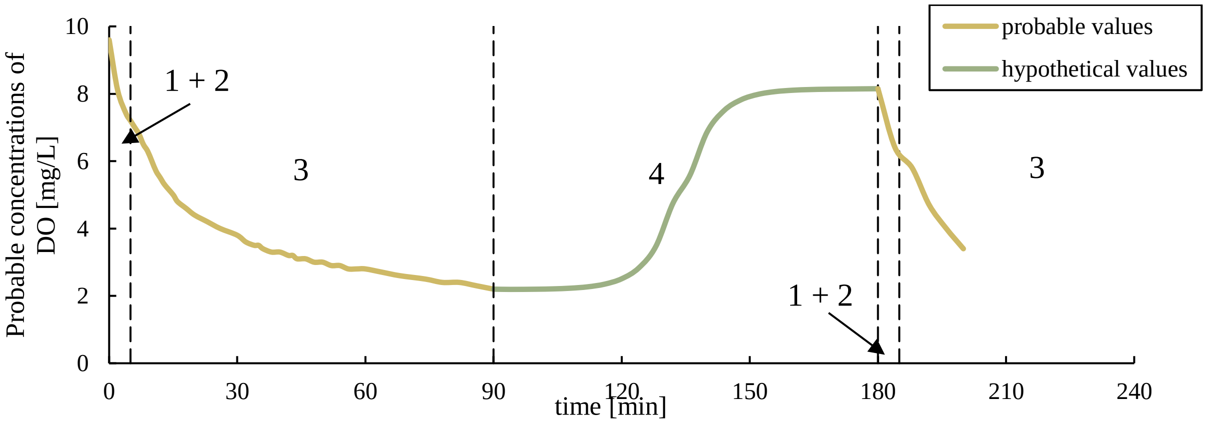
The oxygen's origin comes from the exchanges between the atmosphere and the filter by diffusion and convection effects. They are also a small part present previously in the top part of the VFCW-SB. The convection is the result of a gradient of air pressures in the soil. The gradient results from the effluent water which creates a vacuum which is equalized by air or wastewater. The diffusion depends of the soil capacity to catch oxygen from the atmosphere. The diffusion in small granulometry is lower than in a bigger granulometry (PLATZER, 1999).

The filter empties and recharges with oxygen during a cycle. There are several phases that are developed below:

1. The pumps are on and the tributary reaches the filter surface. (There is a lag between the pumps and the time the effluent leaves the filter, the time difference is about 2 minutes).
2. The tributary infiltrates the VFCW-PS and creates a convection effect. It lasts 5 minutes.
3. The pumps are off and infiltration continues. The convection effect continues, but on the surface the diffusion effect begins.
4. The pumps still are off, the infiltration is finished and the output flow is zero. The filter is at rest. In this phase the oxygen exchanges between the atmosphere and the filter are by diffusion.

The graph in Figure 26 shows the concentration of oxygen in the filter during a cycle. A cycle lasts 180 minutes. The numbers represent the phases that are stated above. The descending curve is drawn from the measurements made. That is, the values are likely. The upward curve is hypothetical because no measure has been made to know for sure the trend.

Figure 26: Variations in dissolved oxygen concentrations during a cycle.



Source: Author

The filter works in phases 1, 2 and 3. It is at rest in the 4th phase. The rest phase corresponds to half a cycle. During this phase the filter is recharged with oxygen. The study is now focused in the concentration of DO at the beginning of the cycle, C_0. Indeed, during the first pulse the filter rested all night. Does the filter reach a level of oxygen saturation during the rest phase?

To answer this last question, Table 20 and Table 21 show the initial concentrations C_0 and maximum C_{max}, respectively on Wednesday and Thursday.

Table 20: Concentrations C_0 and C_{max} - Wednesday

	C_0 mg/L	*C_{max}* mg/L	*t (C_{max})* min
Average	8,21	8,27	0,10
Standard deviation	0,92	0,78	0,32
07/03/2019	7,9	7,9	0
03/04/2019	7,9	7,9	0
17/04/2019	8,5	8,5	0
09/05/2019	7,7	7,7	0
22/05/2019	8,5	8,5	0
12/06/2019	6,1	6,7	1
26/06/2019	8,7	8,7	0
10/07/2019	9,6	9,6	0
24/07/2019	8,8	8,8	0
18/09/2019	8,4	8,4	0

Source: Author

Wednesday, the variations in concentrations are low and usually C_{max} are the initial concentrations with 8.21 mg/L average. Only the C_0 on 12/06/2019 is less than C_{max}. The measurements made on Wednesday correspond to the 1st pulse (8 a.m).

Table 21: Concentrations C_0 and C_{max} - Thursday

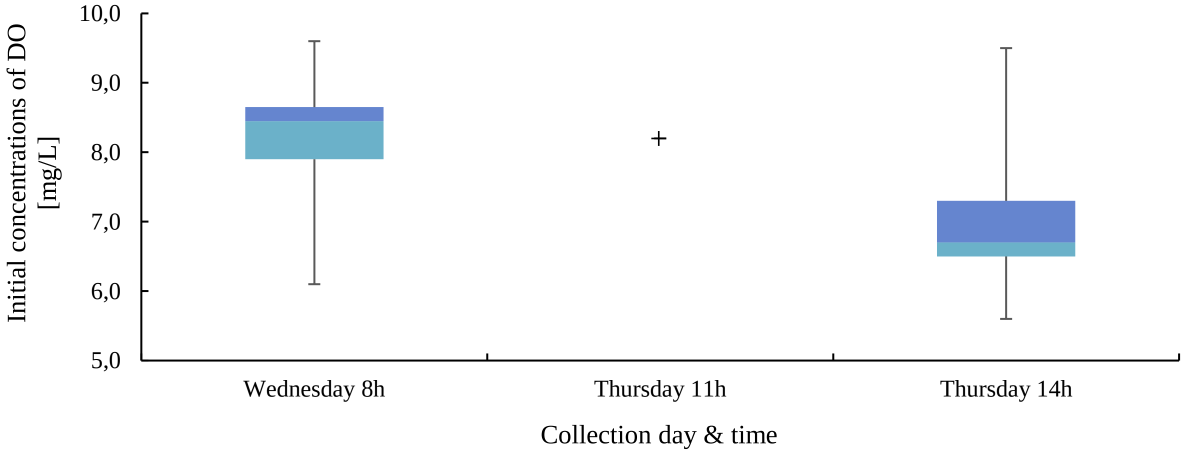
	C_0 mg/L	*C_{max}* mg/L	*t (C_{max})* min
Average	7,12	7,51	1,10
Standard deviation	1,09	0,95	1,29
07/02/2019	5,6	6,4	3
14/02/2019	6,5	6,6	3
14/03/2019	8,2	8,2	0
27/03/2019	6,6	6,6	0
11/04/2019	7,3	8,2	2
25/04/2019	7,3	7,3	0
16/05/2019	6,7	7,3	2
30/05/2019	7,2	7,2	0
20/06/2019	6,3	7,8	1
04/07/2019	9,5	9,5	0

Source: Author

On Thursdays the variations of concentrations C0 are low. The average is 1.09 mg/L lower on Thursdays than Wednesday, with 7.12 mg/L. The maximum concentrations do not necessarily correspond to the initial concentrations. The measurements performed on Thursdays correspond to the 3rd pulse (2 p.m), except the 14/03/2019 which corresponds to the 2nd pulse (11 a.m).

The Figure 27 shows the previous results according to the number of the pulse studied, and the day.

Figure 27: Initial concentrations measured according to the number of the studied pulse, and the day.



Source: Author

Figure 27 seems to confirm that the initial concentration of DO is greater during the first pulse, then in the second and finally in the third. The initial concentration during the 4th pulse would certainly be lower still. The pulse number influences the filter's ability to recharge with oxygen. The hypothesis is confirmed. The filter is quickly charged with oxygen, then the diffusion rate is slowed down to a maximum value. This maximum concentration certainly depends on climatic conditions, such as temperature.

5.2.5 Calculations of oxygen surface charge

The oxygen demand exerted by the incoming wastewater is generally higher than the amount of oxygen available in the system. As a result, oxygen transfer tends to be one of the main processes limiting surface charge in constructed wetland treatment. It is therefore necessary to monitor the amount of oxygen entering the filter (NIVALA et al., 2013). For this we use the flow of oxygen, according to formulas 18, 19 and 20. The filter has a surface *A* of 7.5 m^2.

The table 22 presents the results from dissolved oxygen surface charge calculations in the VFCW-PS filter.

Table 22: Statistics values about dissolved Oxygen surface charge in the VFWC-PS

Date	$M_{DO.input}$ g	j_{pulse} g.m-2	$\overline{J_{pulse}}$ g.m-2.h	j_{daily} g.m-2.day-1
Minimum	54,40	7,25	2,42	29,01
Maximum	79,70	10,63	3,54	42,51
Average x	67,94	9,06	3,02	36,23
Standard variation d	11,36	1,51	0,50	6,06
07/03/2019	54,40	7,25	2,41	29,01
03/04/2019	79,70	10,63	3,54	42,51
22/05/2019	74,48	9,93	3,31	39,72
24/07/2019	63,17	8,42	2,81	33,69

Source: Author

The results in Table 22 indicate that during a pulse the surface charge of oxygen entering the filter is 9,06 $g.m^{-2}$, whereas the average of surface charge is 3,02 $g.m^{-2}.h^{-1}$.

The literature has the habit of expressing the flow of oxygen per day. This better represents the capacity of the filter. The results of Kadlec and Wallace's research, which are published in the Elsevier Review (NIVALA et al., 2013), indicate the following surface charges based on filter configurations:

- horizontal flow systems were estimated to be between 0.5 and 12.9 $g.m^{-2}.d^{-1}$;
- vertical flow systems between 7.9 and 58.6 $g.m^{-2}.d^{-1}$;
- intensified or hybrid systems between 10.9 and 87.5 $g.m^{-2}.d^{-1}$.

It is interesting to compare these results with those of Table 22. The oxygen flux of the VFWC-PS filter is greater than the estimated fluxes of a filter in HFWC configuration. Indeed, the HFWC is saturated in water, so exchanges are rare. In the other hand, the VFWC-PS flows correspond to the filter flows in VFWC configurations and in the hybrid system (VFCW + HFWC).

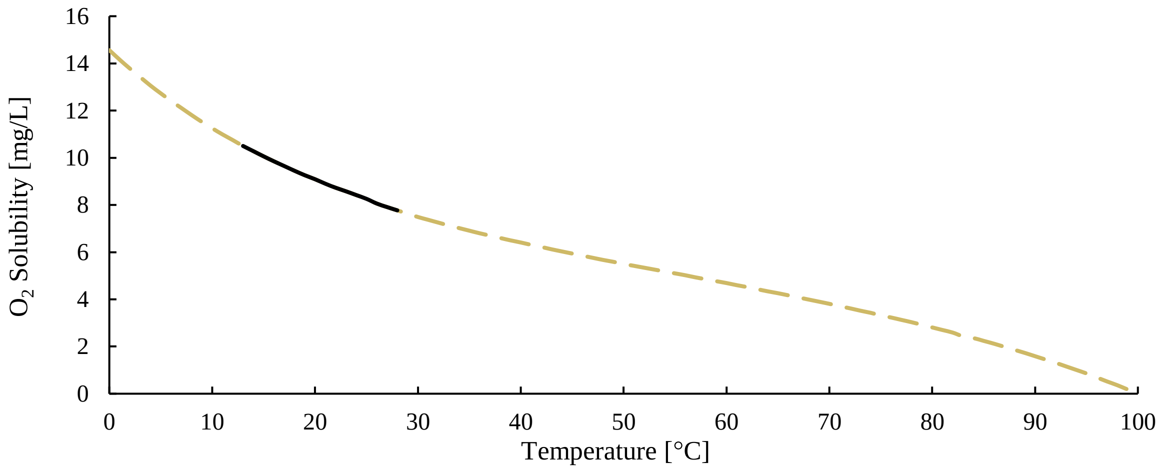
5.3 Discussion

In order to improve the work, several tracks are possible. There are variations related to climatic conditions and tributary variation. The method of collection and the uncertainty of the instruments also influence the results.

5.3.1 Approximations related to physical elements

The tributary is not a stable physical element. Its oxygen content may vary, depending on the weather for example. It has been noticed that during heavy rains the tributary is diluted. There is less oxygen below that comes out of the filter. The volume is also affected. During a rainy episode the volume can double, as it was the case on the 30/05/2019. Temperature also plays a role in the dissolved oxygen content of fluids as shown in the following graph (Figure 28) from the 1888 Winkler method (MOLLE, 2012).

Figure 28: Curve representing the dissolved oxygen concentration as a function of temperature (Wickler, 1888)



Source : Following the Wickler's Method

In Florianópolis the temperatures vary between 13°C and 28°C on average. This temperature range is represented by a continuous black line on the graph of Figure 28. The solubility of oxygen is then between 10.5 mg/L and 7.77 mg/L.

The variations of temperature were not taken into account in this work, being relatively similar (amplitude of 15°C). The results show that temperature variations of 15°C affect the solubility of oxygen of the order of 25%.

The tanque of equalization makes it possible to reduce the variations related to the effluent in terms of composition, and therefore of concentrations. The solution related to the problem of dilution and volume variations is not to take into account these measures. On the March-July period, there was only one point where the rain influenced the measurements.

The time period chosen should cover all possible climatic conditions. In March, at the start of the collection campaign, the weather was summery. In July the conditions were rather winter. Thus, the time period covered all possible climatic conditions.

5.3.2 Approximations related to the measurement method

Other types of uncertainties are related to the measurement method. Indeed, there were two different operators, usually working at different pulses (8 a.m and 2 p.m). A difference between the first daily peak and the 3rd should be noted because at night the filter at 12:30 rest. Oxygen concentrations should therefore be higher because the VFWC-SP has more time to recharge in O_2. A new study started in the GESAD deals about it. They change the frequency of alimentation of effluent with the same daily volume. The objective is to know the better configuration.

Uncertainties in instrument-related measurements occur during measurements of dissolved oxygen volumes and concentrations. The oximeter of the GESAD lab has an uncertainty of the order of 0.1 mg/L. It corresponds to 1.0% to 5.5% of approximation. This error is combined with the errors observed during the calibrations indicate. The approximation error from the volume measurement is more or less 7%. Only these two approximations cumulated give a result with 8% to 12,5%.

Finally, it was noted that there was little data that intersected between manipulations of the first and second data processing. Thus, from 21 collections there are only 4 exploitable points in the final result: the flow of oxygen in the VFWC-SP. Four points are not significant enough. The manipulation should be repeated to confirm the comments made in the part of the results.

6 CONCLUSION

During the first data processing, the results concerning the effluent are close on Wednesdays during the first pulse, and Thursdays during the second/third pulse. The volume variations are lower during the first pulse than during the third. Average total volumes are 170.6 L and 172.0 L respectively. The total DO mass of the pulse is on average slightly lower on Wednesday than on Thursday. The total masses are respectively 842.2 mg and 885.9 mg. This difference therefore influences the average OD concentration of the pulse. The average concentrations of Wednesday and Thursday are 842.2 mg/L and 885.9 mg/L, respectively.

The results from the second data processing indicate that 98.83% of the oxygen that enters in the VFCW-PS is consumed. This study has shown that, in general, the VFCW-PS has a higher removal fee than in 2018. The removal fee is 88.6% for COD, 83.4% for NH_4^+ and 57, 8% for TN.

It was noted that the initial concentrations were higher at the first pulse than during the second and third pulses. The filter may not be able to fully recharge oxygen by diffusion effect, when it is at rest. The average C_0 was measured at 8.21 mg/L on Wednesday during the first pulse of the day, after a rest of 15h. A C_0 of 8.2 mg/L and 7.12 mg L on Thursdays, for the second and third pulses respectively.

The oxygen transfer is evaluated by the flow that enters. The average oxygen flow measured is 36.23 $g.m^{-2}.d^{-1}$ with variations of more or 16% month. This result is very satisfactory because it corresponds to the flow of oxygen found in a VFCW (7.9 to 58.6 $g.m^{-2}.d^{-1}$) or in a hybrid system (10.9 to 87.5 $g.m^{-2}.d^{-1}$). It seems that for a diminished surface we get to have a treatment of an efficiency more and more close. Indeed, a hybrid system occupies twice the surface of a VFCW-PS.

However, during the second data processing, the lack of measurements was felt. With 21 measures initially against only 4 in the end. On the other hand, the main sources of errors come from the measurements used during the first data processing. If measurement collection continues, this error will be decreased. This would be a first way to improve this study to ensure that the results presented are reliable. And secondly, performing the measurements under identical conditions (collection method) would also reduce the approximation to the results. This work has, however, made it possible to improve the collection method and to create a method for obtaining the first results.

7 BIBLIOGRAPHIC REFERENCES

AGÊNCIA NACIONAL DE ÁGUA - ANA. **Atlas Esgotos: Despoluição de Bacias Hidrográficas.** Available on: < http://www.snirh.gov.br/portal/snirh/snirh-1/atlas-esgotos>. Accessed in: 10 aug. de 2019

APHA, AWWA, WEF. **Standard methods for the examination of water and wastewater**. *20st ed. APHA, Washington*. 1998.

APHA, AWWA, WEF. **Standard methods for the examination of water and wastewater**. *21st ed. APHA, Washington*. 2005.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. - ABNT. **NBR 7229:** Projeto, construção e operação de sistemas de tanques sépticos. *Rio de Janeiro*. 1993, 15p.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. - ABNT. **NBR 13.969:** Tanques sépticos - Unidades de tratamento complementar e disposição final dos efluentes líquidos - Projeto, construção e operação. *Rio de Janeiro*. 1997, 60p.

ANTOINE, P., **L'urbanisation en Afrique et ses perspectives**. Revue "Aliment Dans Les Villes*" Marseille*. 1997, 21p.

DIAS, C., **Utilização Da Tecnologia De Wetlands Para Tratamento Terciário: Controle De Nutrientes**. *Universidade de São Paulo*. 2015, 109p.

HEADLEY, T.; NIVALA, J.; KASSA, K.; OLSSON, L.; WALLACE, S.; BRIX, H.; VAN AFFERDEN, M.; MULLER, R. **Escherichia coli removal and internal dynamics in subsurface flow ecotechnologies: effects of design and plants**. *Ecological Engineering*, vol. 61, p.565-574, 2013.

HOFFMANN, H.; WINKER, M., **Technology Review of Constructed Wetlands Subsurface flow constructed wetlands for greywater and domestic wastewater treatment.** *Eschborn: Rotaria*, 2011.

INTERNATIONAL WATER ASSOCIATION - IWA. **Constructed Wetlands for Pollution Control: Processes, Performance, Design and Operation**. *Scientific and Technical Report, London, England: IWA Publishing*, vol. 8, 156p. 2000.

JOHN, O. U. M., & EDUOK, S. I., **Microbiological, Physicochemical and Enzyme Activity Profile of Ayadehe Coastal Wetland Soils, Nigeria**. Journal of Scientific Research and Reports, *University of Uyo*. 2018, 11p.

KIM, B.; GAUTIER, M.; PROST-BOUCLE, S.; MOLLE, P.; MICHEL, P.; GOURDON, R. **Performance evaluation of partially saturated vertical flow constructed wetland with trickling filter and chemical precipitation for domestic and winery wastewaters treatment**. *Ecological Engineering*, vol. 71, p.41-47, 2014.

LANZER, L. M.; WOLF, D. B., **Saneamento básico em Nova Petrópolis/RS: implantação de sistemas descentralizados para o tratamento de esgoto sanitário**. Available on: <http://sites.unifra.br/Portals/36/tecnologicas/2005/Saneamento.pdf>. Accessed in: 16

sept. de 2019. *Disciplinarum Scientia, Santa Maria,* vol. 6, n.1, p.23-40, 2005.

MACHADO, A.-P., URBANO, L., BRITO, A.-G., JANKNECHT, P., SALAS, J.-J., NOGUEIRA, R., **Life cycle assessment of wastewater treatment options for small and decentralized communities**, *Water Science and Technology*, vol. 56, p. 15-22, 2007.

MOLLE, P., **Les filtres plantés de roseaux : évolution de la recherche et tendances actuelles.** Sciences Eaux & Territoires, 10.14758/SET-REVUE.2012.9.04 . hal-00772874. *IRSTEA*, 2012. p.24-31.

MOLLE, P., LIÉNARD, A., GRASMICK, A.; IWEMA, A. **Effect of reeds and feeding operations on hydraulic behavior of vertical flow constructed wetlands under hydraulic overloads**. *Water Research*, vol. 40, n. 3, p.606-612, 2006.

MOLLE, P., IWEMA, A., REEB, G., RABY, D., LESAVRE, J., BOUTIN, C., … POULET, J.-B., **Epuration des Eaux Usées Domestiques par Filtres Plantés de Macrophytes**, *Macrophytes et Traitement Des Eaux.* 2005, 45p.

NIVALA, J., WALLACE, S., HEADLEY, T., KASSA, K., BRIX, H., VAN AFFERDEN, M., & MÜLLER, R., **Oxygen transfer and consumption in subsurface flow treatment wetlands.** Available on line : https://doi.org/10.1016/j.ecoleng.2012.08.028. *Ecological Engineering*. 2013, vol 61, p.544-554.

NUNES DE FREITAS, M., **Avaliação da hidrodinâmica e do desempenho de um wetland construído horizontal componente de um sistema híbrido empregado no tratamento de esgoto sanitário.** *Universidade Federal de Santa Catarina (UFSC), Florianópolis*. 2017, 147p.

OLIJNYK, D. P., **Avaliação Da Nitrificação E Desnitrificação De Esgoto Doméstico Empregando Filtros Plantados Com Macrófitas (Wetlands) De Fluxos Vertical E Horizontal – Sistemas Híbridos**. *Universidade Federal de Santa Catarina (UFSC), Florianópolis*. 2008, 113p.

PELISSARI, C., **Dinâmica Microbiana Nitrificante e Desnitrificante em Wetland Construidos Vertical**. *Universidade Federal de Santa Catarina (UFSC), Florianópolis*. 2017, 213p.

PHILIPPI, L. S., **Saneamento descentralizado como instrumento para o desenvolvimento sustentável**. *Florianópolis: Universidade Federal de Santa Catarina (UFSC)*. 1997, 84 p.

PLATZER, C., **Design recommendations for subsurface flow constructed wetlands for nitrification and denitrification**. *Water Science and Technology, Berlin*. 1999, vol 40, issue 3, 257-263p.

POULET, J., & TERFOUS, A., **Stations D'Epuration a Lits Filtrants Plantes De Macrophytes Waste Water Treatment Plants With Macrophytes**. *Université de Strasbourg, Courrier Du Savoir*, 2004, vol. 5, p.103-106.

PÜTZ, P., **Rapport D'Application, Analyse de Laboratoire & Analyse en Continu, Elements Nutritifs, Composés Azotes**. *HACH LANGE.* 2018, 4p.

SARR, A., THIAM, A., & TIDIANE BÂ, A., **Macrophytes et groupements végétaux aquatiques et amphibies de la basse vallée du ferlo** (Sénégal). Available on line: https://doi.org/10.4314/ajst.v2i1.44651. *African Journal of Science and Technology (AJST)*, 2009, vol. 2, Issue 1, p.89-97

SEZERINO, P. H., ROUSSO, B. Z., PELISSARI, C., SANTOS, M. O. dos, FREITAS, M. N., FECHINE, V. Y., & LOPES, A. M. B., **Wetlands Construídos aplicados no tratamento de esgoto sanitário**. *GESAD, Florianópolis*. 2018, 56p.

TONETTI, A. L., BRASIL, A. L., MADRID, F. J. P. y L., FIGUEIREDO, I. C. S., SCHNEIDER, J., CRUZ, L. M. de O., … MAGALHÃES, T. M., **Tratamento de esgotos domésticos em comunidades isoladas**. *Universidade Estadual de Campinas & Associação Brasileira de Engenharia Sanitaria e Ambiental*. 2018, 153p.

VOGEL, A. L., **Análise inorgânica qualitativa**. *4 ed. Rio de Janeiro: Editora Guanabara*, p.690, 1981.

VON SPERLING, M., **Introdução à qualidade das águas e ao tratamento de esgotos**. 3. ed. *Belo Horizonte: Universidade Federal de Minas Gerais (UFMG)*. 2005, vol. 1.

WINKLER, L. W., **Die Bestimmung des im Wasser gelosten Sauerstoffes**. *Berlin. Germany. Chem. Ges. 21:* p.2843-2853, 1888.

WU, S.; ZHANG, D.; AUSTIN, D.; DONG, R.; PANG, C. **Evaluation of a lab-scale tidal flow constructed wetland performance: oxygen transfer capacity, organic matter and ammonium removal**. *Ecological Engineering*, vol. 37, p.1789-1795, 2011.

ANNEX A – BALANCE SHEET OF THE FIRST DATA PROCESSING

Below table 23 shows the raw values obtained during the first data processing. This made it possible to calculate the statistical values of the table 17.

Table 23: Balance sheet of the first data processing

Date		N°	Volume V	Masses M'	Masses M corrected	Concentration C	V/C	M/C
			L	mg	mg	mg/L		
	Min		149,7	323,7	349,0	1,2	25,1	149,7
	Max		285,6	999,7	1077,8	6,4	233,7	285,6
	Average x		172,56	785,58	846,93	4,89	36,15	173,28
	Standart deviation d		11,17	117,08	126,22	0,71	5,97	11,04
	d/x		6,48%	14,90%	14,90%	14,52%	16,51%	6,37%
	IC 95%		21,90	229,48	247,40	1,39	11,70	21,63
07/02/2019	Thursday		159,6					
14/02/2019	Thursday	1	184,3	787,2	848,7	4,61	40,0	184,3
07/03/2019	Wednesday	2	163,1	598,2	644,9	3,61	49,4	178,5
14/03/2019	Thursday	3	184,0	758,9	818,2	4,45	41,4	184,0
27/03/2019	Thursday	4	175,0	720,7	777,0	4,44	39,4	175,0
03/04/2019	Wednesday	5	168,5	734,8	792,2	4,70	35,8	168,5
11/04/2019	Thursday	6	160,5	952,2	1026,6	6,40	25,1	160,5
17/04/2019	Wednesday	7	168,0	745,6	803,8	4,79	35,1	168,0
25/04/2019	Thursday	8	184,6	890,9	960,5	5,20	35,5	184,6
09/05/2019	Wednesday	9	171,1	614,3	662,3	3,87	44,2	171,1
16/05/2019	Thursday	10	168,8	760,3	819,7	4,85	34,8	168,8
22/05/2019	Wednesday	11	171,3	744,2	802,3	4,68	36,6	171,3
30/05/2019	Thursday	12	285,6	323,7	349,0	1,22	233,7	285,6
12/06/2019	Wednesday	13	161,9	662,5	714,2	4,41	36,7	161,9
20/06/2019	Thursday	14	149,7	657,1	708,5	4,73	31,6	149,7
26/06/2019	Wednesday	15	191,11	861,2	928,5	4,67	42,6	198,8
04/07/2019	Thursday	16	181,53	999,7	1077,8	5,94	30,6	181,5
10/07/2019	Wednesday	17	168,63	823,0	887,3	5,26	32,0	168,6
24/07/2019	Wednesday	18	170,48	903,4	973,9	5,71	29,8	170,5
18/09/2019	Wednesday	19	173,41	926,18	998,5	5,76	30,1	173,4

Source: Author