Ciências Exatas

***Scientia Amazonia*, v. 9, n.3, E26-E44, 2020**
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

PHYSICOCHEMICAL PERFORMANCE IN AN MBR SYSTEM FOR TREATING WASTEWATER

Hanna Louise Luna Rodrigues de Sá[1], Paulo Sergio da Silva[2], Sara Jhulian Monteiro[3], Letícia Lima Moreira[4], Genilson Pereira Santana[5], Cleideane Cunha Costa[6], Erickson Oliveira dos Santos[7], Jorge Átila Damasceno Maia[8], Pedro Luis Sosa González[9], Priscila Pauly Ribas[10], Raimundo Kennedy Vieira[11].

Abstract

Membrane bioreactors (MBRs) are a compact technology used as part of tertiary treatment combined with an activated sludge process for wastewater treatment (WWT) and recycling. These MBR units can perform high efficiency in removing nutrients such as nitrogen, phosphorus, and complete biomass retention without using a secondary clarifier. In this article, operational data and analyzes from WWT that use an MBR will be presented to reuse or recycle the effluent. The results obtained made it practicable to calculate the efficiency of removal of organic matter, the chemical nature of the incrustations, and correlate them to operational problems. The presence of the salt inorganics was confirmed using optical microscopy. These analyses were carried out at five collection points, determining parameters such as BOD, COD, pH, and soluble salt. From the evaluation of these data and the operational data, it was possible to propose an improvement for the effluent treatment plant, thus increasing its efficiency.

Keywords: Bioreactor, Membrane, Fouling, Bacteria.

Desempenho físico-químico em um sistema MBR para tratamento de águas residuais. Os biorreatores de membrana (MBR) são uma tecnologia compacta usada como parte do tratamento terciário combinado com um processo de lodo ativado para tratamento e reciclagem de águas residuais. Essas unidades MBR podem alcançar alta eficiência na remoção de nutrientes como nitrogênio, fósforo e até a retenção completa da biomassa sem a necessidade de um clarificador secundário. Neste artigo, serão apresentados dados operacionais e análises da estação de tratamento de efluentes que usam um MBR para reutilizar ou reciclar o efluente. Com os resultados obtidos, foi possível determinar a eficiência da remoção da matéria orgânica, bem como a natureza química das incrustações e

[1] Undergraduate scholarship students P&D, Manaus, AM, Brazil hannalouiseluna@hotmail.com
[2] Undergraduate scholarship students P&D, Manaus, AM, Brazil, p.silvaa1409@gmail.com
[3] Undergraduate scholarship students P&D, Manaus, AM, Brazil, sarajhulian@gmail.com
[4] Undergraduate scholarship students P&D, Manaus, AM, Brazil llmoreira07@gmail.com
[5] Prof. Titular, ICE, Depto de Química, UFAM, Manaus, AM, Brazil, gsantana2005@gmail.com
[6] Samsung Brasil, Distrito Industrial, Manaus, Brazil cleide.c@samsung.com
[7] Samsung Brasil, Distrito Industrial, Manaus, Brazil erickson.o@samsung.com
[8] Samsung Brasil, Distrito Industrial, Manaus, Brazil jorge.atila@samsung.com
[9] Samsung Brasil, Distrito Industrial, Manaus, Brazil pedro.sosa@samsung.com
[10] Samsung Brasil, Distrito Industrial, Manaus, Brazil priscila.p@samsung.com
[11] FT/UFAM, Manaus, AM, Brazil, correspondence kennedy71@gmail.com

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

correlacioná-las com problemas operacionais. A presença dos sais inorgânicos foi confirmada por microscopia óptica. As análises foram realizadas em cinco pontos de coleta, determinando parâmetros como DBO, DQO, pH, sais solúveis, entre outros. A partir da análise destes dados em conjunto com os dados operacionais, foi possível propor uma melhoria para a estação de tratamento de efluentes, aumentando sua eficiência.

Palavras-chave: Biorreator, Membrana, Incrustações, Bactérias.

Introduction

Systems using membrane bioreactors (MBRs) have become a good alternative for wastewater treatment and reuse (IORHEMEN et al., 2019; NEOH et al., 2016). Since the 1990s, the use of MBRs to treat wastewater has proliferated (SKOUTERIS et al., 2012). This phenomenon of popularity is attributed to a series of advantages that can be mentioned: excellent quality of treated water, relatively simple maintenance, reduced area occupation, longer hydraulic retention time (HRT) and solids retention, less production sludge, high volumetric load rates and the exclusion of the secondary clarification part (MENG et al., 2017; YAMASHITA et al., 2019).

Despite these advantages, the use of MBR is always associated with incrustations in the filtering membrane caused by the deposition of biological material. Additionally, in MBR systems, the formation of a biocake layer with different average particle sizes is observed, this modifies the physicochemical property of the membrane surface, acting on the surface adsorption property (MARROT et al., 2004). This problem increases the operating cost of MBR's and causes a decrease in the quality of wastewater treatment. Additionally, there is an increase in energy demand for the aeration mechanism, which reduces the useful life of the filter membranes in the equipment.

The literature reports several studies (ARIAS et al., 2019; ZHANG & JIANG, 2019; JARMA et al., 2018) that aim to minimize the effects of incrustations on the membrane. Strategically, academic studies have been proposed with the objective of optimizing the cleaning and maintenance process of the membrane to decrease the cost of energy, decrease the cost of the cleaning process and increase the cycle life of the membrane.

In general, the published works involve the use of aeration (CAMPO et al., 2017), flocculants (GKOTSIS et al., 2017) and chemical cleaning (HACIFAZLIOĞLU et al., 2019), as well as the use of nanotechnology (SABALANVAND, HAZRATI, & JAFARZADEH, 2019), process mapping (TAO & LI, 2018), hybrid processes coupled to electrocoagulation and electrophoresis (ENSANO et al., 2016), in addition to other processes involving the modeling and simulation (YANG et al., 2017) of the process for optimization. The results have already been reported about the composition and mechanisms of membrane incrustation, nature of biological material, and interactions between incrustations/membranes, aeration efficiency, chemical washing efficiency, and mathematical modeling of the system.

Literature data show that the analysis of the operational parameters (HABIB et al., 2017), the membrane configuration (BURMAN & SINHA, 2018) and the physicochemical (SHEN et al., 2017) and microbiological (KIM & CHANG, 2019) characteristics of the tributary are

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

decisive to establish the level of incrustations of the membrane, according to the scheme of Figure 1.

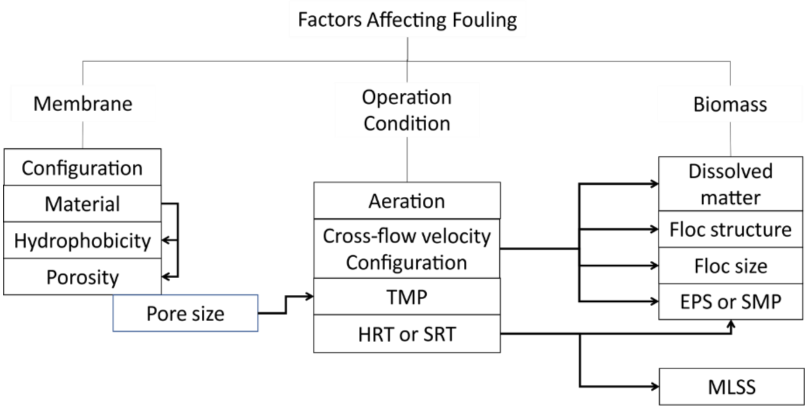

Figure 1. Some factors that influence the appearance of scale in MBR systems. Adapted (SABRINA et al., 2012).

The absence of complementary studies involving chemical, physicochemical, and microbiological parameters resulting from the activity of the sludge indirectly affects the MBR system functioning, since the effects under it, are not known. According to Barak et al. (2020), the microbial activity present in the sludge is the factor responsible for the MBR system's ability to eliminate the organic matter.

As stated by Kellner et al. (2014), the level of degradation of organic matter can be controlled by two variables: biological oxygen demand (BOD5) and Chemical Oxygen Demand (COD), which are physicochemical parameters. Dubber & Gray (2010) observed that the COD/BOD5 ratio that can be a parameter to measure the efficiency of the wastewater treatment (WWT) ranges typically from 1.25-2.50 in wastewater, increasing by values at each stage in the biological treatment. It is because the biodegradable fraction of organic matter undergoes oxidation, and these results in an increase in the ratio of the non-biodegradable fraction.

Besides, as the biodegradation of organic matter occurs, other physicochemical variables such as pH, Mixed liquor suspended solids (MLSS) (MUTAMIM et al., 2012), Dissolved Oxygen (DO) (SARIOGLU et al., 2017), feed for microorganisms (F/M) (AMANATIDOU et al., 2015), total soluble solids (TSS) (NAKHLA et al., 2006) and sludge age (SATYAWALI & BALAKRISHNAN, 2008) are changed. There is also a variation in the BOD/COD ratio. The combination of these variables' values can be used to detect problems and establish procedures to optimize the biodegradation process of organic matter and, consequently, improve the quality of treated wastewater. This work aims to study the physicochemical properties related to the effluent's treatment in an MBR system, to estimate its efficiency and the factors related to foulings in its membrane. Based on this, a study of the physicochemical factors surrounding the membrane and how biomass and operating conditions are necessary to understand and optimize the MBR system's functioning.

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

Relevant parameters in the evaluation of the functioning of MBR System

The factors that can be considered when monitoring the MBR System (CAMPO et al., 2017; DÍAZ et al., 2017; NG et al., 2016) are pH, Dissolved Oxygen (DO), Mixed Liquor Suspended Solids (MLSS), Feed for Microorganisms (F/M), Total Suspended Solids (TSS) and sludge age; these factors need to be monitored daily as they influence the performance of the MBR and the quality of the effluent.

The adequate efficiency of the treated effluent must be obtained by choosing the correct monitoring parameters (ZAZOU et al., 2019). The justification for this continued measurement is to guarantee the survival and excellent performance of the consumption of organic matter made by the bacteria that act in the degradation of the material that makes up the effluent. Besides, this right choice of parameters protects the service life of membranes in MBR systems. Among these factors, we can mention:

Biological Oxygen Demand (BOD)

A Wastewater Treatment Plant (WWTP) is a highly complicated and dynamic system. Therefore, its proper operation and control are essential to protect public and environmental health problems (NOURANI, ELKIRAN & ABBA, 2018). The quality of the raw and treated effluent has a significant impact on the WWTP's operation and performance (AHMADI, MAHDAVIRAD, & BAKHTIARI, 2017). Besides, the changing flow of cargo for treatment influences the whole treatment system. It is difficult to estimate some dominant variables; for example, the biological oxygen demand (BOD) requires a 5-day incubation. It hinders the rapid detection of operational problems. The correct measurement of COD requires a high concentration of organic matter present in the wastewater. This high concentration demands more aeration time and more oxygen supply. Thus, it is important to measure the efficiency of the system through these parameters, which are inversely proportional to the quality of treatment. Measuring them helps to manage the plant and control the quality of the effluents (KIM, et al., 2006). The operational control of the WWTP is complex because of the complexity of the mechanism in the treatment plant, the quality and the strength of the wastewaters (HAMEED et al., 2017).

pH

The pH measurement parameter represents the concentration of H^+ ions in the sample, indicating acidity, neutrality, or alkalinity of the wastewater (von SPERLING, 2005). The pH results are mainly influenced by solids and gases dissolved in the effluent. (GUPTA et al., 2012). The measurement of pH values is of great importance, as they can assist in the measurement of the degree of organic and/or inorganic incrustation in MBR pipes and membranes in the same way as it characterizes water supply and wastewater.

According to von Sperling (2006), the pH can act as an indication for diagnosing the MBR operating. For pH values below 7, in addition to the wastewater having a degree of acidity, this value will favor the appearance of corrosion and wear of membranes. For pH values above 7, the effluent has an alkaline behavior, and this favors the appearance of fouling. Thus, the optimum pH values for the MBR operating range from 6.0-7.0 The same dynamic also applies to processes such as nitrification, which are oxidative and consume effluent alkalinity, decreasing their pH values below 7.0 (TIERLING &

Ciências Exatas

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

KUHLMANN, 2018). When the inversion to more acidic pH values occurs, there is a growth of microorganisms responsible for oxidation.

Mixed liquor suspended solids (MLSS)

The concentration of suspended solids in mixed liquor is one of the key parameters for the operation of membrane bioreactors (YOON, 2015). Yoon (2015) also states that the effect of fouling from the MLSS concentration occurs naturally and can be aggravated by:

- Characteristics of Biomass;
- Concentration above or below of ideal;
- Operating Conditions;
- Characteristics of the membrane module used in the equipment.

According to Judd (2010), the adequate concentration of MLSS in membrane bioreactors must be greater than 8,000 mg L^{-1}, ranging from 10,000 mg L^{-1} to 12,000 mg L^{-1}, these values justify a sufficient amount of material for a good growth of bacteria and their consumption of organic matter. Below-ideal concentrations indicate excessive EPS release.

Dissolved Oxygen (DO)

According to von Sperling (2005), dissolved oxygen is an extremely important factor for the survival of aerobic organisms in nature. For the growth of aerobic bacteria, they use oxygen in their breathing process; this causes the reduction of organic matter, where they are inserted.

The DO parameter in the aquatic environment is used to characterize the effects of water pollution, as well as in sewage treatment plants (HOSSAIN, SARKER & KHAN, 2018). In aerobic reactors, the recommendation for dissolved oxygen is at least 1 mg L^{-1}, and can be introduced by artificial aeration, usually in aeration tanks at treatment plants, but of all the factors that affect aerobic bacteria, the DO concentration is the most significant factor (VERONESE, 2013).

According to the study presented by Veronese, (2013), the reduction of dissolved oxygen causes low oxidation of nitrite in the treatment of biological effluent, favoring the incomplete nitrification of organic matter. In addition, some sediments with low oxygen concentrations were observed, where filamentous bacteria and porous flakes occur. (WILÉN & BALMÉR, 1999). Also, as a result of low concentration of DO, the low transfer of oxygen in the mixed liquor, causes the excessive release of extracellular polymeric substances (EPS) and soluble microbial products (SMP), which increases the occurrence of incrustations in the membrane of bioreactors.

According to Yoon, (2015), when there is the presence of flakes greater than 2 to 3 mg L^{-1} in the concentration of OD and microorganisms such as Nitrosomonas sp., Pseudomonas sp., Xanthomonadaceae, Rhodococcus and Sphingomonas, this demonstrates that there was low nitrification in the studied wastewater. Where there are higher concentrations of dissolved oxygen, resulting from the increased airflow, there is the occurrence of disruption and decrease in size in the observed flakes. (GERMAIN, STEPHENSON & PEARCE, 2005).

F/M Ratio

The F/M ratio influences the amount of food available for degradation. It is directly proportional to the organic matter amount available for the growth of bacteria. It is also a factor of great importance in WWT that uses activated sludge as a biological agent treatment (IORHEMEN; HAMZA; TAY,

Ciências Exatas

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

2016). As "F" corresponds to "food" and "M" to "microorganism," this relationship is associated with the efficiency of the system (CAPPELLO et al., 2016), as it corresponds to the amount of substrate available per unit mass of microorganisms.

According to von Sperling (2006), this parameter fit in prolonged aeration systems for MBR systems. In these systems, the biomass remains for longer retention time in the MBR tank and, ideally, as an MLSS range of 8 to 18 g / L, the F / M ratio should be 0.13 g COD / g of MLSS / day, as maintained by Zsirai et al. (2014). Thus, as stated by Yoon (2015), the lower the values of the F / M ratio, this would lead to the greater the need for food, resulting in greater degradation of organic matter. This raises the need to increase the size of the reactor for the storage of organic matter.

The F / M ratio is given by the following equation (JUDD, 2010):

$$\frac{F}{M} = \frac{(QS_0)}{(VX)} \quad (1)$$

Where, F/M = food-to-microorganism ratio (g BOD/g MLSS/day);
Q = influent flow rate (m^3/day)
S_0 = influent BOD (g/m^3)
X = MLSS in aeration tank (g/m^3)
V = tank volume (m^3)

Yoon (2015) lists the recommended intervals for optimal operation parameter of an MBR system, seen in Table 1.

Table 1. Optimal operation parameter for an MBR system.

Design Parameter	Unit	Range
F/M	g BOD/g MLSS/day	0.04–0.12
MLSS	g/m3	8,000 – 12,000
SRT	days	10 - 20
DO	mg L-1	1 - 2

From Judd (2010).

To calculate the efficiency of matter organic removal could utilize the equation (2):

$$E = \frac{C0 - Ce}{C0} * 100 = \% \quad (2)$$

Where Co is the concentration initial of COD or BOD e Ce is the concentration final of COD or BOD.

According to Yoon, (2015), there are three variables that correlate with each other: the F/M ratio, the solids retention time (SRT) and hydraulic retention time (HRT). When the hydraulic retention time decreases, F/M grows, this ratio is inversely proportional and to keep this ratio working, the sludge must be removed.

Hydraulic Retention Time (HRT)

According to von Sperling (2005), the Hydraulic Retention time (HRT) is defined as the time that the wastewater is inside the reactor to be biodigested. The retention time varies according to the characteristics of the process (CHENG et al., 2018; KAYA et al., 2016), whether it is aerobic, anaerobic or anoxic and the composition of the wastewater and the time indicated for prolonged aeration processes in membrane bioreactors varies from 20 to 30 days.

For the calculation of hydraulic retention time, the following equation is considered (RAHMAN & AL-MALACK, 2006):

$$HRT = \frac{V_R}{[J * A_M\}} \quad (3)$$

So, V_R é the Reactor Volume, A_M is the Membrane Surface Area, and J is the Permeate Flux.

As maintained by Liu & Tay (2007), HRT with low values favor cell granulation and improve the stability of biomass since it increases the pressure of cell growth through natural selection

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

with short cycles. As claimed by Viero, Sant & Jr (2008), concerning membrane systems, the HRT is always higher, allowing more excellent retention of solutes and, consequently, better removal efficiency.

On a report of Yoon (2015), for MBR systems that treat domestic sewage, the hydraulic retention time varies from 2 to 4 hours in aeration tanks and from 1 to 2 hours in membrane tanks. However, in tanks with aeration and membrane together, if there are no anoxic and aerobic tanks connected, the HRT varies from 3 to 6 hours. For systems connected with the anoxic tank, the HRT varies from 1 to 2 hours inside the tank.

Sludge Retention Time (SRT)

According to Meng et al. (2009), among the membrane operating factors that influence the membrane fouling are SRT, HTR, aeration, and the permeate flow.

There is a relationship between SRT and HTR, with the retention time being the time necessary for solids and water to pass, respectively, through the reactor. They are directly proportional, as at the same time, as the hydraulic retention time increases, the age of the sludge increases, and the growth of bacteria. This impairs the filtration flow of the membrane by increasing the deposit of particles on it, which causes the membrane fouling. On the other hand, if the detention time is reduced, there will also be no degradation of biomass, causing a decrease in the efficiency of the WWTP (FUCHS et al., 2003).

The operation of MBR in longer SRTs is capable of leading to an internal blockage of the membrane pores, possibly due to higher concentrations of inorganic fouling (HUANG, ONG & NG, 2008). In addition, in longer SRTs, there may be an increase in the concentrations of carbohydrates and proteins that are soluble insoluble in the SMP. As well as may result in less particle flocculation and changes in particle size and, consequently, accelerate membrane fouling (HUANG, ONG & NG, 2011). Regarding HRTs, Huang, Ong & Ng (2011) concluded that a decrease in their values increases the growth of biomass, leading to the accumulation of SMP inside the MBR tank, leading to an acceleration of the fouling of the membrane process.

The aerobic SRT can be calculated by the following equation:

$$\mathrm{SRT} = \frac{V_{Ar}}{Q_{Ar}} \qquad (4)$$

Where: V_{Ar} = Aerobic tank volume and Q_{Ar} = Inlet flow of the arerobic tank.

Materials and Methods

The experimental study unit was performed utilizing an MBR System, which is located at an industry of the Industrial Pole of Manaus, with capacity of 1.140 m³/day. It is a domestic wastewater treatment plant (WWTP), designed to treat sewage from a contingent of up to 15 thousand employees. The collections were made at five collect points, which were chosen because they are the backbone of the WWTP (Figure 2): Septic Tank, Aerobic Tank, Anoxic Tank and MBR Reactor and Final Effluent.

The arrangement of samples performed to study the physicochemical parameters is shown in Table 2. In the plan, shown in Table 2, each run corresponds to the five samplings performed in each of the five collection points presented in Figure 2 (septic tank, aerobic tank, anoxic tank, MBR, and final effluent outlet).

***Scientia Amazonia*, v. 9, n.3, E26-E44, 2020**
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

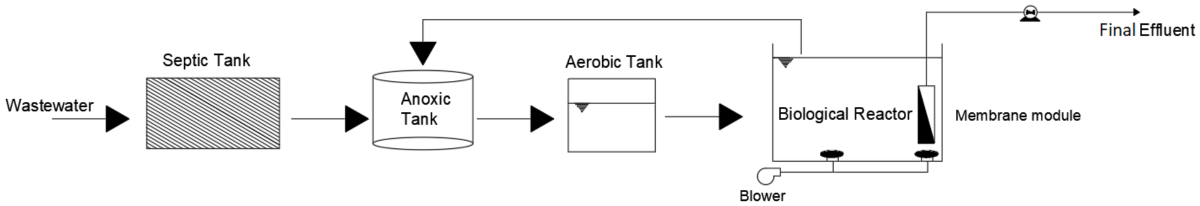

Figure 2. Flowchart of the steps studied in the MBR system in the original size. Operating temperature bioreactor, anoxic and aerobic tanks: 32 ° C; Inlet flow in the system: 240 m^3 / day; Recirculation flow: 75 m^3 / h; Operating pressure: 0.981 bar; Feed input flow: 18 ~ 20 m^3 / h; Volume of the anoxic tank: 275 m3; Aerobic tank volume: 849 m^3; Aeration rate: an average of 42 m^3 / min volume of the bioreactor: 44 m^3; Tubular type bioreactor with hollow fiber membrane; membrane material: polyvinylidene fluoride; a system with two modules; each module contains five lines with 12 filters on each line; discharge flow from the MBR: average 10 m^3 per hour; final effluent output flow: 26 m^3 / h

Table 2. Experimental planning of physicochemical parameters

Physicochemical Parameter	Runs	Samples
BOD	- 6	24 (inlet and outlet) 30
DO	11	55
pH	- 5	12 (just in the outlet) 25
Soluble Salts	8	40

BOD Analysis

The BOD measurement was carried out in two different periods and with specific objectives. To check if the pH meets the established by 357 CONAMA (BRAZIL 2005), monthly collections were made at the outlet (final effluent) for one year, totaling 12 collections. In order to verify the behavior of each of the five stages of the MBR system, which were considered most relevant in this study: septic tank, aerobic tank, anoxic tank, MBR and final effluent outlet; collections were carried out at weekly intervals, not coinciding with the monthly collections, totaling six collections. The samples were collected using a manual collector at each stage studied. The samples were stored in an amber bottle under refrigeration until the time of analysis. The analyzes were performed on the Hach Respirometry equipment, following the recommendations of APHA (2011) and were coded with the numbering from S_1 to S_{12}.

DO analysis

DO measurements were performed by collections performed three times a week. The samples were collected using a manual collector, each run comprised the five samples from each of the five stages of the studied MBR system, totaling 11 runs. The samples were stored in an amber bottle under refrigeration until the time of analysis. The analyzes were performed following the recommendations of APHA (2011).

pH Analysis

The pH measurements were performed in two different periods and with specific objectives. The first collet data was made to check if the pH meets the established by 357 CONAMA (BRAZIL 2005). To obtain these data were done monthly collections at the outlet (final effluent) over one year, totaling 12 collections. The second arrangement of data was made to verify the behavior of each of the five stages of the MBR system. The collections performed three times a week. The samples were collected using a manual collector; each run comprised the five samples from each of the five stages of the studied MBR system, totaling six runs. The samples were stored in an amber bottle under refrigeration until the time of analysis. The analyzes were performed in a Bench pHmeter of the brand AZ, following the recommendations of APHA (2011).

Soluble salts analysis

Soluble salts measurements were performed by collections performed three times a week. The samples were collected using a manual collector, each run comprised the five samples from each of the five stages of the studied MBR system, totaling 8 runs. The samples were stored in an amber bottle under refrigeration until the time of analysis. The analyzes were performed following the recommendations of APHA (2011).

Characterization of the treatment system

The reading of the operational parameters, in the studied system, enabled the results presented in Table 3.

Results and Discussion

The presentation of the results starts with the operational results obtained by the station's sensors.

F/M Ratio results

With the data provided by the station's operating system (Table 3), it was possible to determine the F/M ratio.

F/M = [(240 m^3/day) x (230 g/m^3)]/[(44 m^3) x (4500 g/m^3)] = 0,28 g BOD / g MLSS / day

Table 3. Operation parameter directly measured at the WWTP.

Description	Data
Hydraulic retention time	1h16min
Sludge retention time	17 days
Recirculation rate	75m^3/h
MLSS concentration in the no bioreactor	4500 g/m^3
Chemical cleaning frequency	90 days
Backwash frequency	7 days

The WWTP presented a standard F / M value corresponding to 0.28. This value was above the range of 0.04–0.12 g BOD / g MLSS / day. A high F/M rate implies a reduced STR and consequently, an increase in incrustations (YOON, 2015). The consequence of the decrease in STR implies a greater removal of sludge from the system, which implies a low MLSS. The terms high and low utilized in this paragraph refer to the intervals shown in Table 1. The set of factors, low MLSS (4500 g / m^3), high F/M (0.28 BOD / g MLSS / day), low STR (17 days) and low HTR (1h16 min) lead to increased fouling.

Grelier et al. (2006) carried out work with parameters very close to those presented in this study. Among the studied parameters, the MLSS was considered to be 4.900 g L^{-1} for the STR of 15 days. The authors concluded that the rapid inlay of the membrane with low SRT was due to the high concentration of SMP based on polysaccharides in the mixed liquor. This matches the type of food served to employees in the studied industry, rich in carbohydrates. Other study that collaborates with the impact that a low SRT and high F M impacts on the increase of incrustations was carried out by Wu et al. (2013). These authors used transmembrane pressure (TMP) as a fouling indicator, observed an increase from 5 to 20 times from the lowest to the highest F/M ratio (0.17 and 0.50 g COD / g MLSS / day).

Ciências Exatas

***Scientia Amazonia*, v. 9, n.3, E26-E44, 2020**
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

This study's results so far tend to indicate a higher incidence of fouling and loss of operational efficiency, which can be confirmed by analyzing the physicochemical parameters' data.

Physicochemical parameters

DO results

Figure 3 shows the DO values for the studied MBR System steps.

The arrangement of samples performed to study the physicochemical parameters is shown in Table 2.

In the plan, shown in Table 2, each run corresponds to the five samplings performed in each of the five collection points presented in Figure 2 (septic tank, aerobic tank, anoxic tank, MBR, and final effluent outlet).

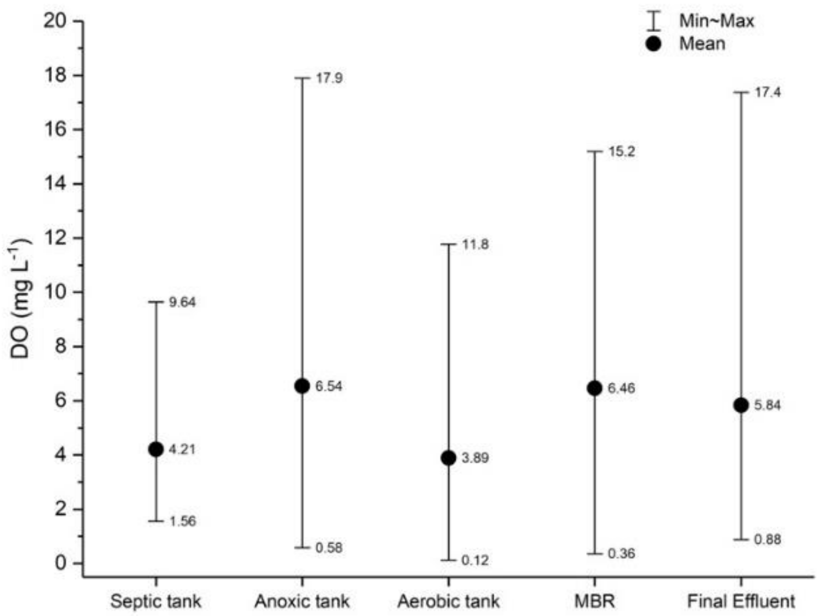

Figure 3. DO concentration in the studied MBR system steps.

When analyzing the data presented in Figure 3, a high DO average is observed in all stages of the studied MBR System. It is already a consensus that the optimum DO concentration range is between 1 and 2 mg L^{-1} (YOON, 2015). It is also known that high DO can provide incrustations both positive and negative. However, if high DO is caused by excessive aeration, it can lead to a high shear of the flake particles, which will be divided into smaller and smaller pieces, which will increase the incrustations.

A study by Jin et al. (2006), with two DO concentrations: low (<0.1 ppm) and high (> 3.0 mg / L), led them to verify that the increasing rate of TMP was much lower in the reactor with high DO. In other words, even although there was an increase in fouling for low DO values, it was lower for high DO values.

Even with the high DO concentration caused by excessive aeration, which does not affect fouling less than the low DO rates, the energetic course would not justify this procedure. Generally, the cost of sludge treatment and the cost of aeration were inversely proportional to each other, which means that the cost of sludge treatment is minimized when the cost of aeration is maximized and vice versa.

So, the relationship between SRT (sludge retention time) and aeration must be considered (YOON, KIM & YEOM, 2004).

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

As can also be seen in Figure 3, there is a constant change in the dissolved oxygen throughout the treatment process of WWT, but it does not present very high values, and the final effluent can be disposed of without significant problems in the environment. Because following São Paulo (1976) for direct release into the receiving body of DO effluents, in any sample, not less than 5 mg L^{-1}.

pH

The result of the monthly pH analysis showed a value of 6.48 ± 0.86, which statistically complies with the requirements of 357 CONAMA (BRAZIL, 2005). The results relate to the monitoring of the process of five stages of the MBR system are presented in Figure 4. It was carried out to see if it would provide any additional information on the treatment process's functioning.

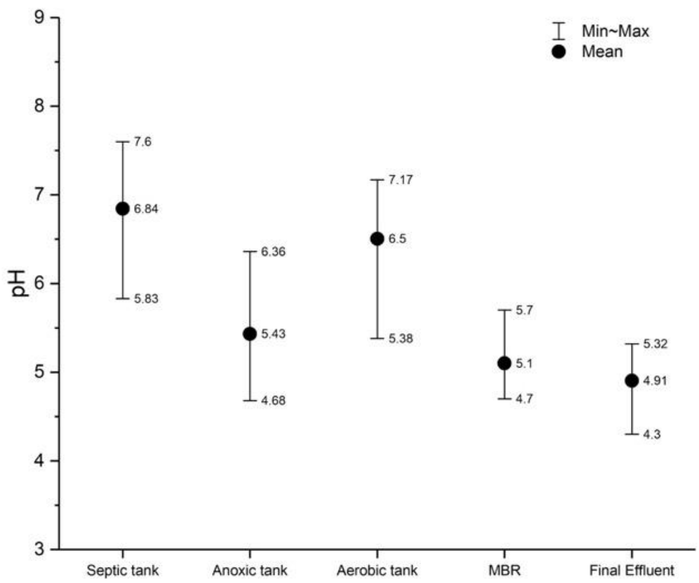

Figure 4. pH measurement in the studied MBR system steps.

The data showed in Figure 4 shows that the pH tends to decrease in the anoxic tank and the MBR. This fact demonstrates that the connection between the anoxic tank and the MBR by reflux is not working correctly. Its function would be to degrade the nitrate, and in this process, the pH would rise, which does not occur here. However, the values found in the MBR, with these results, are compromising the growth of bacteria present in the bioreactor (SHEN et al., 2015). These values of pH below 6 in the bioreactor demonstrate that nitrification can occur in the bioreactor. It means the need to correct the process entry and preserve the membrane (MENG et al., 2017).

The importance of pH control is related to the effluent's flocculation, when the optimum pH level, which should be between 6.0 to 9.0 (as required by 357 CONAMA (BRAZIL 2005), for launching into water bodies). It reflects suitable flocculation and later decantation, these impacts on the excellent performance of biological processes (Ly et al., 2018; Xu et al., 2019). However, observing the values presented by MBR always operates with acidic pH levels, this causes corrosivity in the membrane pipes with an increase in the incrustations of dissolved

Ciências Exatas

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

salts. Then, the analysis of soluble salts at the WWTP is shown in Figure 5.

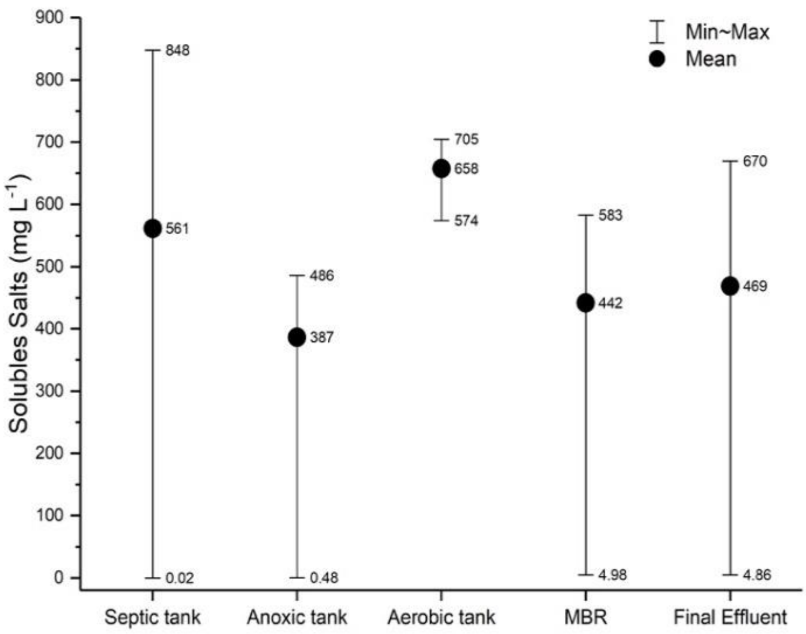

Figure 5 - Values of Soluble Salts from the WWT samples.

As shown in Figure 5, despite the presence of soluble salts in the MBR samples with average values ranging from 387 to 561 m L^{-1}, these inorganic salts obstruct the membrane filtration pores more stops and cleanings in the operational procedure of the WWT. Dreszer et al. (2013) and Chen et al. (2019) also verified that soluble salts in other stages of the process are not so significant, as the filtering membrane will absorb most of these components. Although the treatment is carried out in all treatment units, there is a predominance of inorganic salts present throughout the process, and this ends up causing a blockage of the MBR filter membranes, it also was verified by Han et al. (2017) and Han et al. (2019).

BDO results

The presentation of the results begins with the analysis of the monthly monitoring data of the BOD data. These data are shown in Figure 6.

From Figure 6, during the WWT monitoring period, its efficiency has always been higher than the minimum value required by the standard. The 430 CONAMA (BRAZIL, 2011), establishes a minimum removal of 60% of BOD_5 so that the effluent can be released into the receiving body. However, despite the relatively high efficiency, it is below expectations for the MBR System. According to Barbosa (2017), an efficiency greater than 97% is expected for the MBR System.

***Scientia Amazonia*, v. 9, n.3, E26-E44, 2020**
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

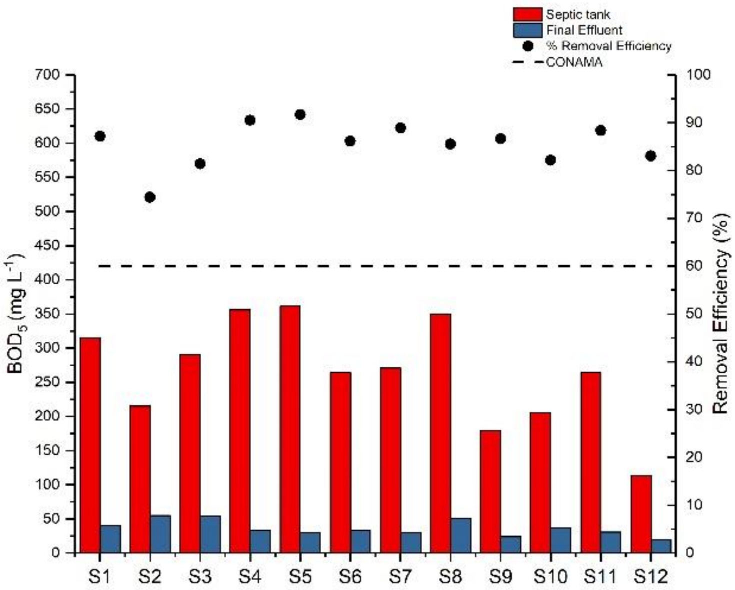

Figure 6. BOD_5 monthly measurements at the entry and exit in the MBR system and its % removal efficiency.

Thus, the BOD_5 results for other steps of the MBR system can help identify the deviations that led to these results. Monitoring data for the most relevant parts of the WWTP is shown in Figure 7.

As observed by the data in Figure 7, most of the consumption of organic matter occurs in the aerobic tank (129 mg L^{-1}). However, the MBR system is not working properly, because the values decrease from the septic tank to the aerobic tank, increasing the BOD value in the membrane reactor and in the final effluent. This behavior should not be observed, because according to Dubber & Gray (2010), the value of BDO should decrease at each stage of the process, as the biodegradable fraction of organic matter is being oxidized.

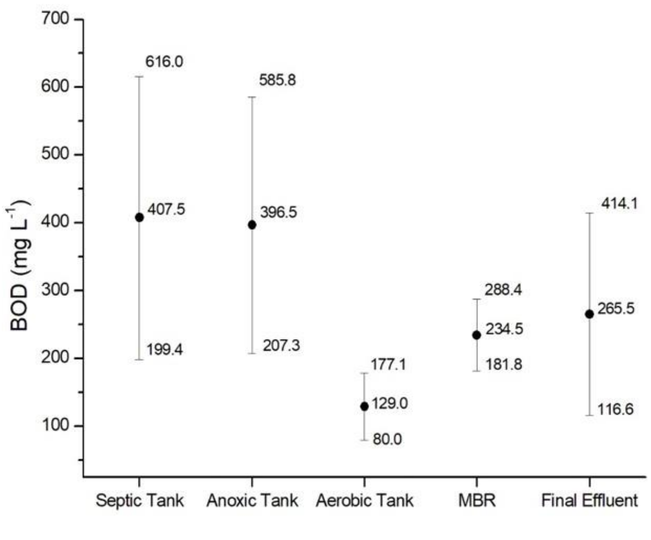

Figure 7 – BOD_5 results obtained in mg L^{-1}

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

Conclusion

The results of the analysis of the physical-chemical indicators evaluated made it possible to compare them with the parameters established by the legislation. These results indicated that the processes operate within normality and, therefore, meet the criteria established by 357 CONAMA (BRAZIL, 2005) and 430 CONAMA (BRAZIL, 2011).

Although the parameters meet the standards, observing the analysis of the physical-chemical parameters in the monitoring of the MBR system demonstrates that there is an opportunity to improve the process. When comparing these results with the plant's operational data, it is confirmed that the MLSS could reach values of 8000 mg L^{-1}, which would lead to the improvement of operational parameters. The increase in the MLSS will lead to the natural adjustment of the F/M ratio to decreasing values, impacting the increase in the STR and HTR values.

Both operational and physical-chemical data indicate the growth of fouling in the MBR. The DO adjustment, to the standard expected for an MBR system, will bring energy savings and less likelihood of scale formation. The F / M alignment will balance the reaction between food and microorganism, leading to the adequacy of BOD values in the system.

Adjusting the pH will also improve efficiency in the conversion of organic matter and consequently, in the BOD values, in addition to helping to minimize the risk of corrosion throughout the entire MBR system.

A more consistent cleaning schedule for the system and adapted, as suggested in the manual, can minimize this problem.

Thus, it appears that the objective of the work was achieved, as the aim was to make a diagnosis of the system and indicate ways to improve its performance.

Acknowledgements

This study, according for in Article 48 of Decree n° 6.008/2006, was funded by Samsung Electronics of Amazonia Ltda, under the terms of Federal Law n° 8.387/1991, through agreement n° 004, signed with UFAM.

Divulgation

This article is unpolished. The authors and reviewers are not related to any conflict of interest during their evaluation. Therefore, the journal Scientia Amazonia holds the copyright reserved, has authorization and permission from authors for the dissemination of this article by electronic means.

References

Ahmadi, M. M., Mahdavirad, H., & Bakhtiari, B. (2017). Multi-criteria analysis of site selection for groundwater recharge with treated municipal wastewater. *Water Science and Technology*, *76*(4), 909-919.

Amanatidou, E., Samiotis, G., Bellos, D., Pekridis, G., & Trikoilidou, E. (2015). Net biomass production under complete solids retention in high organic load activated sludge process. Bioresource technology, 182, 193-199.

APHA. (2011). Standard Method for Examination of Water and Wastewater. In American Public Health Association.

Arias, A., Vallina, I., Lorenzo, Y., Komesli, O. T., Katsou, E., Feijoo, G., & Moreira, M. T. (2019). Water footprint of a decentralised wastewater treatment strategy based on membrane technology. In Environmental Water Footprints (pp. 85-119). Springer, Singapore.

Barak, H., Brenner, A., Sivan, A., & Kushmaro, A. (2020). Temporal distribution of microbial community in an industrial wastewater treatment system following crash and during recovery periods. Chemosphere, 127271.

Barbosa, I. M. (2017). Avaliação do uso de membranas de ultrafiltração modificadas com nanopartículas de argila para tratamento de esgotos. 197.

BRAZIL. CONAMA Resolution 430 of March 13, 2011. National Environment Council. Available at: <http://www2.mma.gov.br/port/conama/legiabre.cfm?codlegi=646>. Accessed on: August 8th. 2020.

BRAZIL. CONAMA Resolution 357 of March 17, 2005. National Environment Council. Available in: < http://pnqa.ana.gov.br/publicacao/resolucao_conama_n_357.pdf>. Accessed on: August 8th. 2020.

Burman, I., & Sinha, A. (2018). A review on membrane fouling in membrane bioreactors: control and mitigation. In Environmental Contaminants (pp. 281-315). Springer, Singapore.

Campo, R., Capodici, M., Di Bella, G., & Torregrossa, M. (2017). The role of EPS in the foaming and fouling for a MBR operated in intermittent aeration conditions. Biochemical engineering journal, 118, 41-52.

Cappello, S., Volta, A., Santisi, S., Morici, C., Mancini, G., Quatrini, P., ... & Torregrossa, M. (2016). Oil-degrading bacteria from a membrane bioreactor (BF-MBR) system for treatment of saline oily waste: Isolation, identification and characterization of the biotechnological potential. International Biodeterioration & Biodegradation, 110, 235-244.

Chen, L., Hu, Q., Zhang, X., Chen, Z., Wang, Y., & Liu, S. (2019). Effects of salinity on the biological performance of anaerobic membrane bioreactor. Journal of Environmental Management, 238, 263–273. https://doi.org/10.1016/j.jenvman.2019.03.012

Cheng, C., Zhou, Z., Pang, H., Zheng, Y., Chen, L., Jiang, L. M., & Zhao, X. (2018). Correlation of microbial community structure with pollutants removal, sludge reduction and sludge characteristics in micro-aerobic side-stream reactor coupled membrane bioreactors under different hydraulic retention times. Bioresource technology, 260, 177-185.

Díaz, O., González, E., Vera, L., Macías-Hernández, J. J., & Rodríguez-Sevilla, J. (2017). Fouling analysis and mitigation in a tertiary MBR operated under restricted aeration. Journal of membrane science, 525, 368-377.

Dreszer, C., Vrouwenvelder, J. S., Paulitsch-Fuchs, A. H., Zwijnenburg, A., Kruithof, J. C., & Flemming, H. C. (2013). Hydraulic resistance of biofilms. Journal of Membrane Science, 429, 436–447. https://doi.org/10.1016/j.memsci.2012.11.030

Dubber, D., & Gray, N. F. (2010). Replacement of chemical oxygen demand (COD) with total organic carbon (TOC) for monitoring wastewater treatment performance to minimize disposal of toxic analytical waste. Journal of Environmental Science and Health, Part A, 45(12), 1595–1600. https://doi.org/10.1080/10934529.2010.506116

Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric Method for Determination of Sugars and Related Substances. Analytical Chemistry. https://doi.org/10.1021/ac60111a017

Ensano, B., Borea, L., Naddeo, V., Belgiorno, V., de Luna, M. D., & Ballesteros Jr, F. C. (2016). Combination of electrochemical processes with membrane bioreactors for wastewater treatment and fouling control: a review. Frontiers in Environmental Science, 4, 57.

Fuchs, W., Binder, H., Mavrias, G., & Braun, R. (2003). Anaerobic treatment of wastewater with high organic content using a stirred tank reactor coupled with a membrane filtration unit. Water Research, 37(4), 902-908.

Germain, E., Stephenson, T., & Pearce, P. (2005). Biomass characteristics and membrane aeration: toward a better understanding of membrane fouling in submerged membrane bioreactors (MBRs). *Biotechnology and bioengineering*, *90*(3), 316-322.

Gkotsis, P. K., Batsari, E. L., Peleka, E. N., Tolkou, A. K., & Zouboulis, A. I. (2017). Fouling control in a lab-scale MBR system: comparison of several commercially applied coagulants. Journal of environmental management, 203, 838-846.

Grelier, P., Rosenberger, S., Tazi-Pain, A. 2006. Influence of sludge retention time on membrane bioreactor hydraulic performance. Desalination 192:10–17.

Gupta, V. K., Ali, I., Saleh, T. A., Nayak, A., & Agarwal, S. (2012). Chemical treatment technologies for waste-water recycling—an overview. *Rsc Advances*, *2*(16), 6380-6388.

Habib, R., Asif, M. B., Iftekhar, S., Khan, Z., Gurung, K., Srivastava, V., & Sillanpää, M. (2017). Influence of relaxation modes on membrane fouling in submerged membrane bioreactor for domestic wastewater treatment. Chemosphere, 181, 19-25.

Hacıfazlıoğlu, M. C., Parlar, İ., Pek, T. Ö., & Kabay, N. (2019). Evaluation of chemical cleaning to control fouling on nanofiltration and reverse osmosis membranes after desalination of MBR effluent. Desalination, 466, 44-51.

Hameed, M., Sharqi, S. S., Yaseen, Z. M., Afan, H. A., Hussain, A., & Elshafie, A. (2017). Application of artificial intelligence (AI) techniques in water quality index prediction: a case study in tropical region, Malaysia. *Neural Computing and Applications*, *28*(1), 893-905.

Han, Q., Li, W., Trinh, T. A., Liu, X., & Chew, J. W. (2017). A network-based approach to interpreting pore blockage and cake filtration during membrane fouling. Journal of Membrane Science, 528, 112–125.https://doi.org/10.1016/j.memsci.2017.01.026

Han, Q., Trinh, T. A., & Chew, J. W. (2019). Cake formation of bidisperse suspensions in dead-end microfiltration. Journal of Membrane Science, 577, 31–40. https://doi.org/10.1016/j.memsci.2019.01.048

Hossain, L., Sarker, S. K., & Khan, M. S. (2018). Evaluation of present and future wastewater impacts of textile dyeing industries in Bangladesh. Environmental Development, 26, 23-33.

Huang, Z., Ong, S. L., & Ng, H. Y. (2008). Feasibility of submerged anaerobic membrane bioreactor (SAMBR) for treatment of low-strength wastewater. Water Science and Technology, 58(10), 1925-1931.

Huang, Z., Ong, S. L., & Ng, H. Y. (2011). Submerged anaerobic membrane bioreactor for low-strength wastewater treatment: effect of HRT and SRT on treatment performance and membrane fouling. Water research, 45(2), 705-713.

Iorhemen, O. T., Hamza, R. A., & Tay, J. H. (2016). Membrane bioreactor (Mbr) technology for wastewater treatment and reclamation: Membrane fouling. Membranes, 6(2), 13–16. https://doi.org/10.3390/membranes6020033

Iorhemen, O. T., Hamza, R. A., Zaghloul, M. S., & Tay, J. H. (2019). Aerobic granular sludge membrane bioreactor (AGMBR): Extracellular polymeric substances (EPS) analysis. Water Research, 156, 305–314. https://doi.org/10.1016/j.watres.2019.03.020

Jarma, Y. A., Parlar, İ., O Pek, T., Kayral, K., Kabay, N., Ö Yiğit, N., ... & Yüksel, M. (2018). Study on Operational Conditions to Minimize Membrane Fouling in Membrane Bioreactor (MBR) System for Wastewater Treatment-Preliminary Pilot Tests. Journal of Membrane Science and Research, 4(4), 212-217.

Jin, Y. L., Lee, W. N., Lee, C. H., Chang, I. S., Huang, X., & Swaminathan, T. (2006). Effect of DO concentration on biofilm structure and membrane filterability in submerged membrane bioreactor. Water Research, 40(15), 2829-2836.

Judd, S. (2010). *The MBR book: principles and applications of membrane bioreactors for water and wastewater treatment*. Elsevier.

Kaya, Y., Bacaksiz, A. M., Golebatmaz, U., Vergili, I., Gönder, Z. B., & Yilmaz, G. (2016). Improving the performance of an aerobic membrane bioreactor (MBR) treating pharmaceutical wastewater with powdered activated carbon (PAC) addition. Bioprocess and biosystems engineering, 39(4), 661-676.

Kim, J. R., Ko, J. H., Im, J. H., Lee, S. H., Kim, S. H., Kim, C. W., & Park, T. J. (2006). Forecasting influent flow rate and composition with occasional data for supervisory management system by time series model. Water science and technology, 53(4-5), 185-192.

Kim, W. K., & Chang, I. S. (2019). Modeling of the effect of current density and contact time on membrane fouling reduction in EC-MBR at different MLSS concentration. Journal of Korean Society of Water and Wastewater, 33(2), 111-119.

Kellner, R. L., Membrana, B. À., & Móvel, D. E. L. (2014). Biorreator à membrana de leito móvel em bateladas sequenciais para a remoção de nutrientes e matéria orgânica de efluentes sanitários.
Liu, Y. Q., & Tay, J. H. (2007). Characteristics and stability of aerobic granules cultivated with different starvation time. Applied microbiology and biotechnology, 75(1), 205-210.

Ly, Q. V., Nghiem, L. D., Cho, J., & Hur, J. (2018). Insights into the roles of recently developed coagulants as pretreatment to remove effluent organic matter for membrane fouling mitigation. Journal of Membrane Science, 564, 643–652. https://doi.org/10.1016/j.memsci.2018.07.081

Marrot, B., Barrios-Martinez, A., Moulin, P., & Roche, N. (2004). Industrial wastewater treatment in a membrane bioreactor: a review. *Environmental progress*, *23*(1), 59-68.

Meng, F., Zhang, S., Oh, Y., Zhou, Z., Shin, H. S., & Chae, S. R. (2017). Fouling in membrane bioreactors: An updated review. In Water Research. https://doi.org/10.1016/j.watres.2017.02.006

Meng, F., Chae, S. R., Drews, A., Kraume, M., Shin, H. S., & Yang, F. (2009). Recent advances in membrane bioreactors (MBRs): membrane fouling and membrane material. Water research, 43(6), 1489-1512.

Mutamim, N. S. A., Noor, Z. Z., Hassan, M. A. A., & Olsson, G. (2012). Application of membrane bioreactor technology in treating high strength industrial wastewater: a performance review. Desalination, 305, 1-11.

Nakhla, G., Lugowski, A., Patel, J., & Rivest, V. (2006). Combined biological and membrane treatment of food-processing wastewater to achieve dry-ditch criteria: pilot and full-scale performance. Bioresource technology, 97(1), 1-14.

Neoh, C. H., Noor, Z. Z., Mutamim, N. S. A., & Lim, C. K. (2016). Green technology in wastewater treatment technologies: Integration of membrane bioreactor with various wastewater treatment systems. Chemical Engineering Journal, 283, 582–594. https://doi.org/10.1016/j.cej.2015.07.060

Ng, K. K., Shi, X., Ong, S. L., Lin, C. F., & Ng, H. Y. (2016). An innovative of aerobic bio-entrapped salt marsh sediment membrane reactor for the treatment of high-saline pharmaceutical wastewater. Chemical Engineering Journal, 295, 317-325.

Nourani, V., Elkiran, G., & Abba, S. I. (2018). Wastewater treatment plant performance analysis using artificial intelligence–an ensemble approach. *Water Science and Technology*, *78*(10), 2064-2076.

Rahman, M. M., & Al-Malack, M. H. (2006). Performance of a crossflow membrane bioreactor (CF–MBR) when treating refinery wastewater. Desalination, 191(1-3), 16-26.

Sabalanvand, S., Hazrati, H., & Jafarzadeh, Y. (2019). Adsorption of organic compounds on the Fe_3O_4 nanoparticles for forestalling fouling in membrane bioreactor. Journal of Water and Environmental Nanotechnology, 4(2), 88-96.

Sabrina, N., Mutamim, A., Zainon, Z., Arif, M., Hassan, A., & Olsson, G. (2012). Application of membrane bioreactor technology in treating high strength industrial wastewater : a

performance review. 305, 1–11. https://doi.org/10.1016/j.desal.2012.07.033
São Paulo. Decree No 8,468, of September 8, 1976, from the State of São Paulo, it provides for the prevention and control of moderation of the environment. Available at: < https://www.al.sp.gov.br/repositorio/legislacao/decreto/1976/decreto-8468-08.09.1976.html>. Accessed in: August 8th, 2020.

Sarioglu, M., Sayi-Ucar, N., Cokgor, E., Orhon, D., Van Loosdrecht, M. C. M., & Insel, G. (2017). Dynamic modeling of nutrient removal by a MBR operated at elevated temperatures. Water research, 123, 420-428

Satyawali, Y., & Balakrishnan, M. (2008). Treatment of distillery effluent in a membrane bioreactor (MBR) equipped with mesh filter. Separation and purification Technology, 63(2), 278-286.

Shen, L. G., Lei, Q., Chen, J. R., Hong, H. C., He, Y. M., & Lin, H. J. (2015). Membrane fouling in a submerged membrane bioreactor: Impacts of floc size. Chemical Engineering Journal, 269, 328–334. https://doi.org/10.1016/j.cej.2015.02.002

Shen, L., Wang, X., Li, R., Yu, H., Hong, H., Lin, H., ... & Liao, B. Q. (2017). Physicochemical correlations between membrane surface hydrophilicity and adhesive fouling in membrane bioreactors. Journal of colloid and interface science, 505, 900-909.

Skouteris, G., Hermosilla, D., López, P., Negro, C., & Blanco, Á. (2012). Anaerobic membrane bioreactors for wastewater treatment: A review. Chemical Engineering Journal, 198–199, 138–148. https://doi.org/10.1016/j.cej.2012.05.070

Tao, Y., & Li, C. (2018). Application of PSO-RBF Neural Network in MBR Membrane Pollution Prediction. In 2018 Eighth International Conference on Instrumentation & Measurement, Computer, Communication and Control (IMCCC) (pp. 873-877). IEEE.

Tierling, J., & Kuhlmann, H. (2018). Emissions of nitrous oxide (N2O) affected by pH-related nitrite accumulation during nitrification of N fertilizers. Geoderma, 310, 12-21.

Veronese, C. G. Estudo de tratabilidade dos efluentes da refinaria do vale do Paraíba (REVAP). 2013. 282 p. Dissertação (Mestrado em Engenharia de Processos) Universidade de Caxias do Sul, Rio Grande do Sul, 2013.

Viero, A. F., Sant, G. L., & Jr, A. (2008). Is hydraulic retention time an essential parameter for MBR performance? Aline F. Viero, Geraldo L. Sant'Anna Jr. ∗ Chemical Engineering Program, COPPE/Federal University of Rio de Janeiro, P.O. Box 68502, CEP 21941-972, Rio de Janeiro, Brazil.

von SPERLING, M. (2005). Introdução à qualidade das águas e ao tratamento de esgotos: princípios do tratamento biológico de águas residuárias. *Belo Horizonte: UFMG*, *452*.

Wilén, B. M., & Balmér, P. (1999). The effect of dissolved oxygen concentration on the structure, size and size distribution of activated sludge flocs. *Water Research*, *33*(2), 391-400.
Wu, B., Kitade, T., Chong, T.H., Lee, J.Y., Uemura, T., Fane, A.G. 2013. Flux-dependent fouling phenomena in membrane bioreactors under different food to microorganisms F/M ratio. Sep. Sci. Technol. 48(6):840–848.

Xu, R., Yu, Z., Zhang, S., & Meng, F. (2019). Bacterial assembly in the bio-cake of membrane bioreactors: Stochastic vs. deterministic processes. Water Research, 157, 535–545. https://doi.org/10.1016/j.watres.2019.03.093

Zsirai, T., Wang, Z. Z., Gabarrón, S., Connery, K., Fabiyi, M., Larrea, A., & Judd, S. J. (2014). Biological treatment and thickening with a hollow fibre membrane bioreactor. Water research, 58, 29-37.

Zazou, H., Afanga, H., Akhouairi, S., Ouchtak, H., Addi, A. A., Akbour, R. A., ... & Jada, A. (2019). Treatment of textile industry wastewater by electrocoagulation coupled with electrochemical advanced oxidation process. Journal of Water Process Engineering, 28, 214-221.

Zhang, W., & Jiang, F. (2019). Membrane fouling in aerobic granular sludge (AGS)-

Scientia Amazonia, v. 9, n.3, E26-E44, 2020
Revista on-line http://www.scientia-amazonia.org
ISSN:2238.1910

membrane bioreactor (MBR): Effect of AGS size. Water research, 157, 445-453.

Yang, M., Yu, D., Liu, M., Zheng, L., Zheng, X., Wei, Y., ... & Fan, Y. (2017). Optimization of MBR hydrodynamics for cake layer fouling control through CFD simulation and RSM design. Bioresource technology, 227, 102-111.

Yamashita, K., Itokawa, H., & Hashimoto, T. (2019). Demonstration of energy-saving membrane bioreactor (MBR) systems. Water Science and Technology, 79(3), 448–457. https://doi.org/10.2166/wst.2019.068

Yoon, S. H. (2015). Membrane bioreactor processes: principles and applications. CRC press.