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Artículos Científicos

Biomasa de origen vacuno en la remoción de contaminantes básicos en un reactor discontinuo secuencial

Biomass of Bovine Origin in the Removal of Basic contaminants in a Sequential Batch Reactor

Biomassa de origem bovina na remoção de contaminantes básicos em reator em batelada sequencial

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Resumen

El propósito en la presente investigación fue evaluar el potencial del estiércol de ganado vacuno como biomasa en suspensión en reactores discontinuos secuenciales (SBR) a diferentes tiempos de retención hidráulica para mejorar la remoción de contaminantes básicos de agua residual doméstica. Los reactores SBR para el experimento fueron construidos por triplicado con capacidad operativa de 720 L. Al estiércol vacuno a emplear como biomasa en suspensión se le determinó (promedio ± *DE*) la biomasa seca (72.3 ± 6.2 %), humedad (27.7 ± 6.2 %), pH (7.8 ± 1.3) y materia volátil (0.15 ± 0.05 kg mv/kg estiércol). El lodo microbiano (10 kg de estiércol) se preparó en el SBR con agua residual doméstica estabilizándose en 21 días aproximadamente. Posteriormente, se realizaron experimentos con tiempos de retención hidráulica (TRH) a 15 h, 20 h y 25 h, y se contrastaron con el agua residual cruda. El SBR fue operado con un volumen de lodo activo de 0.29 m^3, un volumen de intercambio 0.43 m^3 (59.7 %), tiempo de sedimentación de 1 h, tiempo de reacción de 5 h, SSVLM de 1600 mg/L, TMRC de 6 días y Y de 0.21 kg/célula/lb. Los datos experimentales de calidad del agua (influente y efluente) fueron analizados estadísticamente con pruebas no paramétricas, al no cumplir postulados de normalidad y homocedasticidad con la prueba de Kruskal-Wallis, y el contraste de medianas de Mann-Whitney con valor $p < 0.05$, que indica diferencias estadísticamente significativas entre las medianas con un nivel de 95.0 % de confianza de los tratamientos evaluados. El tratamiento más eficiente fue el TRH 20 h, con (mediana ± *DE*) turbiedad 9.2 ± 0.84 UNT, color con 286.2 ± 34.53 UC, pH 6.15 ± 0.77, temperatura del agua de 29.9 ± 1.57 °C, conductividad eléctrica (CE) de 1103.35 ± 102.1 µS/cm, oxígeno disuelto (OD) con 4.2 ± 0.42 mg/L, demanda química de oxígeno (DQO) con 35.6 ± 2.98 mg/L y sólidos suspendidos totales (SST) de 26.35 ± 1.20 mg/L. Para el TRH 15 h se obtuvo eficiencias de remoción para DQO de 75.8%, en el TRH 20 h 92.4% (DQO); mientras que el TRH 25 h presentaron eficiencias de 64.5% (DQO). Esta alternativa de tratamiento cumple con los criterios de descarga a cuerpos receptores establecidos por la NOM-001-SEMARNAT-1996. Los SBR con biomasa vacuna pueden ser empleados con confianza para pequeños caudales discontinuos, ya que no utiliza equipos sofisticados, no requiere reactivos dañinos secundarios y su único requerimiento es la energía eléctrica.

Palabras clave: demanda química de oxígeno, eficiencia de remoción, estiércol, tiempo de retención hidráulica.

Abstract

The purpose of the present investigation was to evaluate the potential of cattle manure as biomass in suspension in sequential discontinuous reactors (SBR) at different hydraulic retention times, to improve the removal of basic contaminants from domestic wastewater. The SBR reactors for the experiment were built in triplicate with an operating capacity of 720 L. The bovine manure to be used as biomass in suspension was determined (average ± SD) the dry biomass (72.3 ± 6.2%), humidity (27.7 ± 6.2%), pH (7.8 ± 1.3) and volatile matter (0.15 ± 0.05 kg mv / kg manure). The microbial sludge (10 kg of manure) was prepared in the SBR with domestic residual water, stabilizing in approximately 21 days, subsequently experiments with hydraulic retention times (TRH) were performed at 15, 20 and 25 hours, contrasting with the residual water raw. The SBR was operated with an active mud volume of 0.29 m^3, an exchange volume of 0.43 m^3 (59.7%), settling time of 1 h, reaction time of 5 h, SSVLM of 1600 mg/L, TMRC of 6 days and Y of 0.21 kg / cell / lb. The experimental data on water quality (influent and effluent) were statistically analyzed with non-parametric tests, as they did not meet normality and homoscedasticity postulates with the Kruskal-Wallis test and the Mann-Whitney test of medians with a P-value <0.05, indicating statistically significant differences between the medians with a level of 95.0% confidence of the evaluated treatments. The most efficient treatment was HRT 20 h, with (median ± SD) Turbidity 9.2 ± 0.84 UNT, Color with 286.2 ± 34.53 UC, pH 6.15 ± 0.77, water temperature of 29.9 ± 1.57 ° C, Electrical conductivity (EC) of 1103.35 ± 102.1 µS cm^{-1}, dissolved oxygen (DO) with 4.2 ± 0.42 mg/L, chemical oxygen demand (COD) with 35.6 ± 2.98 mg/L and total suspended solids (TSS) of 26.35 ± 1.20 mg/L, For the 15-hour HRT, removal efficiencies for COD of 75.8% were obtained, in the 20-hour HRT 92.4% (COD); while the 25-hour HRT presented efficiencies of 64.5% (COD). This treatment alternative meets the criteria for discharge to receptor bodies established by NOM-001-SEMARNAT-1996. SBRs with vaccine biomass can be used with confidence for small discontinuous flows, since they do not use sophisticated equipment, do not require secondary harmful reagents and their only requirement is electrical energy.

Keywords: chemical oxygen demand, removal efficiency, manure, hydraulic retention time.

Resumo

O objetivo da presente investigação foi avaliar o potencial do esterco bovino como biomassa suspensa em reatores sequenciais em batelada (SBR) em diferentes tempos de retenção hidráulica para melhorar a remoção de contaminantes básicos de águas residuais domésticas. Os reatores SBR para o experimento foram construídos em triplicata com capacidade operacional de 720 L. O esterco bovino a ser utilizado como biomassa suspensa foi determinada (média ± DP) a biomassa seca (72,3 ± 6,2%), umidade (27,7 ± 6,2%), pH (7,8 ± 1,3) e matéria volátil (0,15 ± 0,05 kg mv / kg de esterco). O lodo microbiano (10 kg de esterco) foi preparado no SBR com esgoto doméstico, estabilizando em aproximadamente 21 dias. Posteriormente, foram realizados experimentos com tempos de retenção hidráulica (TRH) às 15h, 20h e 25h, e contrastados com água residuária bruta. O SBR foi operado com volume de lodo ativo de 0,29 m^3, volume de troca de 0,43 m^3 (59,7%), tempo de sedimentação de 1 h, tempo de reação de 5 h, SSVLM de 1600 mg/L, TMRC de 6 dias e Y de 0,21 kg / célula / lb. Os dados experimentais de qualidade da água (afluente e efluente) foram analisados estatisticamente com testes não paramétricos, pois não atenderam aos postulados de normalidade e homocedasticidade com o teste de Kruskal-Wallis, e as medianas de Mann-Whitney contrastam com p <0,05, o que indica diferenças estatisticamente significativas entre as medianas com nível de confiança de 95,0% dos tratamentos avaliados. O tratamento mais eficiente foi TRH 20 h, com (mediana ± DP) turbidez 9,2 ± 0,84 NTU, cor com 286,2 ± 34,53 UC, pH 6,15 ± 0,77, temperatura da água de 29,9 ± 1,57 ° C, condutividade elétrica (CE) de 1103,35 ± 102,1 µS/cm, oxigênio dissolvido (DO) com 4,2 ± 0,42 mg/L, demanda química de oxigênio (DQO) com 35,6 ± 2,98 mg/L e sólidos suspensos totais (SST) de 26,35 ± 1,20 mg/L. Para as 15 h TRH foram obtidas eficiências de remoção para DQO de 75,8%, no TRH de 20 h 92,4% (DQO); enquanto o TRH 25 h apresentou eficiências de 64,5% (COD). Esta alternativa de tratamento atende aos critérios de descarga para órgãos receptores estabelecidos pela NOM-001-SEMARNAT-1996. Os SBRs com biomassa bovina podem ser usados com segurança para pequenos fluxos descontínuos, uma vez que não utiliza equipamentos sofisticados, não requer reagentes secundários nocivos e sua única exigência é a energia elétrica.

Palavras-chave: demanda química de oxigênio, eficiência de remoção, esterco, tempo de retenção hidráulica.

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Introduction

Urban and rural communities, in search of economic growth, have multiplied the consumption of materials and, by extension, have increased the generation of waste. This has resulted in water pollution: they have modified it physically, chemically and biologically, which has generated an imbalance that affects both the productivity of the systems and human health. (Ghizellaoui and Ghizellaoui, 2010).

The activated sludge process as wastewater treatment was developed in Manchester, England, in 1914. By 1920, several plants began their operation in the United States of America, however, the extensive use of this system occurred until 1940. The first Researchers noted that the amount of biodegradable matter entering the system affected the rate of metabolism. The designs at that time were totally empirical and the hydraulic retention time (HRT) of the aeration tank was one of the first design parameters. Short retention times for low organic loads and long retention times for high organic loads were generally selected. Subsequently, criteria related to the organic load and microorganisms of the system emerged, and the relationship known today as food / microorganism (A / M) was reached (National Water Commission [Conagua], 2016).

The Sequential Batch Reactor (SBR) is an activated sludge system for wastewater treatment (domestic and industrial) using fill and discharge cycles. In a reactor it is necessary to guarantee an oxygen level in the aeration tank of a minimum of 2 mg / L and a maximum of 4 mg / L. The level of suspended solids in the mixed liquor at low water level should be kept around 4000 mg / L for domestic wastewater, in order to provide starvation conditions in the aeration tank with which a stabilized purge sludge can be obtained. . The treatment cycle ranges from 4 h to 24 h, with an A / M ratio of 0.15-0.6 days-1. Compared to other aerobic systems, the SBR has a high biomass production, has little aeration reduction capacity and requires high operator attention. (Environmental Protection Agency [EPA], 1999).

In this regard, Li, Healy, Zhan and Rodgers (2008) evaluated the performance of a 10 L volume SBR in the treatment of slaughterhouse wastewater. The wastewater presented a tributary with 4672 ± 952 mg / L of chemical oxygen demand (COD), 356 ± 46 mg / L of total nitrogen (NT) and 29 ± 10 mg / L of total phosphorus (PT). The complete cycle lasted eight hours and consisted of four phases: filling (7 min), reaction (393 min), sedimentation (30 min) and emptying / inactive (50 min). During the reaction phase, the reactor was intermittently aerated with an air supply of 0.8 L / min four times at 50 min intervals. At a effluent organic load rate of 1.2 g COD L-1 d-1, the average effluent concentrations of COD, NT and PT were 150 mg / L, 15 mg / L and 0.8 mg / L, respectively. This represented a removal of 96%, 96% and 99% for COD, NT and PT, respectively. The phases showed that the biological absorption of phosphorus occurred in the first aeration period and the removal of nitrogen was carried out in the following reaction time, by means of nitrification and partial denitrification. Nitrogen balance analysis indicated that denitrification and biomass synthesis contributed 66% and 34% to the elimination of NT, respectively (Li et al., 2008).

Another study, that of Pire, Palmero, Araujo and Díaz (2010), evaluated the efficiency of a SBR in the removal of organic matter, nutrients and heavy metals using a mixture of two fractions of discharges from a tannery. The authors compared the removal efficiencies obtained by feeding the reactor with diluted and concentrated effluents, varying the TRH in 8 and 12 hours. During the reaction time, anoxic and oxic phases were combined. It was obtained that the removal of pollutants was statistically higher when diluted effluents were used (COD £ 1000 mg / L and [Cr3 +] £ 10 mg / L), regardless of the TRH used: the highest removal was achieved during the anoxic phase. The removals did not show statistical difference between them, oscillating for the treatments with diluted tributaries between 82.5% and 84.2% for the COD; 58.0% and 73.9% for P-PO43– and 51.2% and 53.9% for Cr. The elimination of N was carried out by assimilation because the nitrifying microorganisms were more sensitive and inhibited their activity against the presence of chromium and high concentrations of organic matter. Chromium removal was achieved by precipitation or adsorption in the mud, so it was essential to control the pH in the reactors between 7.5 and 8.5 units. (Pire *et al.*, 2010).

The objective of wastewater treatment is the removal of polluting substances in order to avoid negative effects on aquatic ecosystems and ensure that the water quality is adequate according to its potential uses or discharge into receiving bodies (Ministry of the Environment and Natural Resources [Semarnat] -Conagua, sf). In Mexico, there are 746 activated sludge treatment plants and its variants, including the SBR, which represents 30.12% of the treatment plants installed in the country; They have an installed treatment capacity of 94 485.8 L / s (53.09%) and an operating capacity of 67 059.7 L / s (55.47%) of wastewater generated in the country (Conagua, 2015). These plants have had stoppages and low removal efficiencies in both organic matter and nutrients, as they present process uncontrols (variations in pH, temperature, load and flow) and lose the suspended crop, being these responsible for the degradation of organic matter and others pollutants. To reshape the crop, these systems can take up to six months to stabilize and establish good removal efficiency.

The main difference between a continuous flow reactor and a discontinuous flow reactor is that in the former the process develops in a spatial sequence, while in the second the process develops in a temporal sequence (Nájera, 2012). One of the most important advantages of sequential batch reactors is that all unit operations and processes are carried out within the same reaction tank, which means a substantial economic saving in capital costs as there is no need for clarifiers and other additional equipment (Noyola, Morgan and Güereca, 2013). Since the decantation occurs in the same reaction tank, the loss of sludge is significantly reduced, allowing better control of the concentration of the activated sludge. Due to the above, this study evaluates the potential of the use of cattle manure in the formation of biomass in suspension for a SBR in the removal of basic contaminants under different hydraulic retention times. With this information, a procedure is generated for the generation of active biomass in this type of reactors that allows optimizing the times and the removal of pollutants with raw material available at low cost.

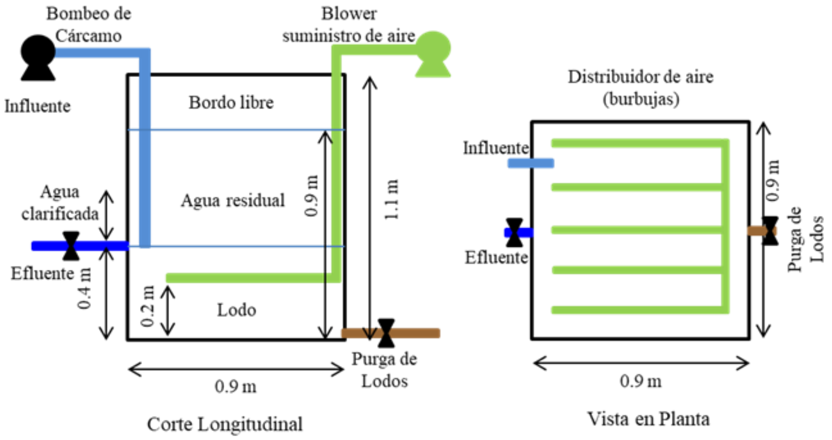
Materials and method

The SBR experimental system was built in the Academic Division of Biological Sciences (DACBiol) of the Universidad Juárez Autónoma de Tabasco (UJAT) (N 17º 59´ 26 ″ and 17º 59´ 17 ″; W 58´ 16 ″ and 92º 58´ 37 ″). The wastewater to be treated came from the concentrating station of the sanitary facilities in that space. The bovine manure for the formation of active biomass was collected in cattle fields (17 ° 57´ 06.24 ″ N and 92 ° 57´ 18.47 ″ W), in the municipality of Centro, Tabasco. The water quality parameters of the experiments were determined in the Water Technology Laboratory of said institution.

SBR Features

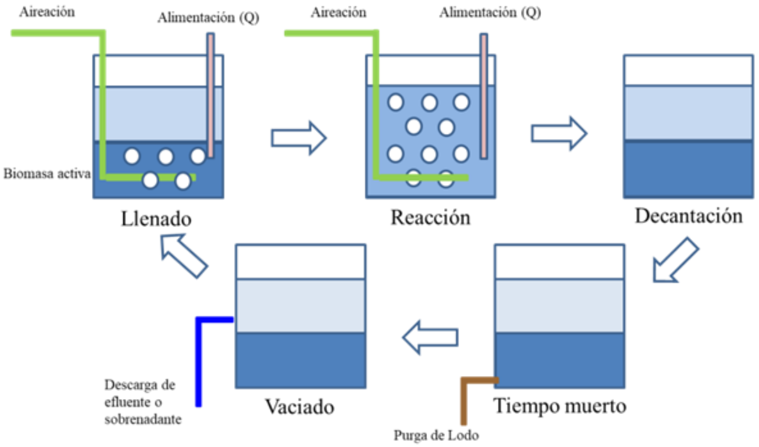
The SBR reactors were designed and built under criteria established by the EPA (1999), Crites and Tchobanoglous (2000), Araya, Vera, Morales, López and Vidal (2014) and Conagua (2016). These have dimensions of 0.9 m long x 0.9 m wide x 1.1 m high. They were built with commercial plastic containers and aluminum protection, with a capacity of 1000 L, but they were operated with a volume of 720 L. Inside an air diffusion system was installed supplied with a Blower equipment whose power was one horsepower (HP). The water supply was from the sanitary wastewater receiving station using a ¼ HP pump. The internal pailer consists of one-inch polyvinyl chloride (PVC) hydraulic pipes and fittings, such as valves, elbows, tees, connectors, etc. For oxygen dispersion, pipes with 0.2 cm diameter holes were installed. These diffusers fixed at the bottom of the tank have the ability to inject the air generating fine bubbles that promote better oxygenation of the water (figure 1). Within the SBR all the stages were carried out, that is, the preparation of the microbial sludge, the treatment of residual water (in batches), the clarification or decantation of the treated water were carried out. The activated sludge was reused (in the same reactor), in order to maintain the adequate concentration of activated sludge for subsequent treatments. The SBR had an inlet for raw wastewater by pumping, an outlet for the sludge at the bottom of the chamber, and an outlet for the extraction of treated and clarified water (figure 2).

Figura 1. Arreglo del reactor discontinuo secuencial y complementos auxiliares



Fuente: Elaboración propia

Figura 2. Fases de funcionamiento del sistema SBR; un solo tanque lleva a cabo las funciones de igualación, aireación y sedimentación en una secuencia de tiempo



Fuente: Elaboración propia

Microbial sludge preparation

The inoculum (culture of microorganisms) was generated from the fecal matter of cattle. This manure, once collected in the field, was determined for humidity, pH and volatile solids. Subsequently, 10 kg of manure was added to the SBR to make up 290 L of residual water, which formed a mixture of between 2000 and 3000 mg / L of volatile suspended solids in the mixed liquor (SSVLM) (Levin and Gealt, 1997 ; Méndez, Miyashiro, Rojas, Cotrado and Carrasco, 2004). The culture was kept in acclimatization for 21 days before the experiments. It began with aeration, keeping them stabilized for five days. During this period, parameters such as pH, turbidity, color, temperature and dissolved oxygen (DO) were monitored. After five days, the sludge purge was performed; the water was emptied once a day for 16 days until the stabilization process was completed (Conagua, 2016). In the SBR, the maximum input concentration (Co) was estimated to be around 600 mg / L of COD and the output concentration (Ct) less than 30 mg / L. The residual water presented a reaction order equal to one (n = 1) (Crites and Tchobanoglous, 2000). The HRTs of the SBR, for this study, were established at 15, 20 and 25 hours. After stabilization, the reactor was fed to a volume of 720 L and the experiment was started. Next, in table 1, the operating characteristics of the system are presented.

Tabla 1. Parámetros de operación del SBR en la fase experimental.

Parámetro	Valor	Unidad
Q entrada	0.0875	m^3/h
Núm. de tanques (réplicas)	3	
TRH	15-20-25	h
DQO soluble	460.0	mg/L
Correlación DBO_5-DQO	0.6	
Vol. operación	0.72	m^3
Vol. de Lodos	0.29	m^3
Vol. de intercambio	0.43	m^3
% Intercambio	59.7	
Tiempo de llenado	10	Min
Tiempo de ciclo	30	Min
Tiempo de sedimentación	1	h
Tiempo de decantación	1	h
Tiempo muerto	1	h
Tiempo de reacción	5	h
SSLM	2,000	mg/L
SSVLM	1600	mg/L
TMRC (ϴc)	6	días
Y = sustrato (DQO) consumidos	0.21	kg/célula/lb
Kd	0.06	$Días^{-1}$
Sólidos efluentes biodegradables	80.0	%

Fuente: Elaboración propia

Water quality parameters

The water quality parameters analyzed during the evaluation were temperature, turbidity, color, pH, EC, DO, total suspended solids (TSS) and COD. These were measured at the beginning and end in each of the experiments, taking as an input sample the raw residual water (influent) obtained from the concentrator, which was called HRT 0 h, and as an output sample (effluent) the one obtained after of each different experiment, TRH 15 h, 20 h and 25 h. The methods used to measure the parameters were the following: temperature (2550 Temperature, 2017), EC (2510 Conductivity, 2017) and pH (4500-H + pH Value, 2017) were measured with the Hanna HI98129 equipment. The turbidity was determined by the EPA method 180.1, TC-300e, ISO7027, TC-300i, using the Hanna HI 98703 equipment with a precision of 0.01 NTU. The color was determined using the 2120 Color standard (2017), with the Lamotte equipment and with a precision of 0.1 UC. The DO was determined by the standard 4500-H + pH Value (2017). COD by the EPA method 410.4 (O'Dell, 1993). The SSTs were determined by the NMX-AA-034-SCFI-2001 standard (Ministry of Economy, s. F.). In the experimental phase with the SBR, the control parameters and basic contaminants were measured in the period August-December 2018. Each experiment (15 h, 20 h and 25 h) was carried out six times in triplicate (with their respective replicas), measuring influent and effluent. According to the sampling campaign, 36 samples were obtained per experiment (treatment and two replicates); a total of 108 samples were analyzed for the three treatments.

Removal Efficiency

Removal efficiencies were calculated with the following equation:

$$ER\ (\%) = \left(\frac{CE - CS}{CE}\right) X\ 100$$

Where ER is the percentage of removal efficiency, CE is the inlet concentration, CS is the concentration obtained at the exit of the SBR; was applied to each pollutant or parameter (Vázquez y López, 2011).

Experimental design and statistical analysis

It was required to use a randomized one-factor design to carry out the analysis of the treatment systems (TRH) and their controls (raw wastewater). For each of these, it was run in triplicate (August-December 2018). The analyzed parameters did not present a normal and homoscedastic behavior, for which a non-parametric analysis was determined using the Kruskal-Wallis test and Mann-Whitney medians contrast. To establish the existence of a statistically significant difference between the medians, the p value <0.05 was established. Finally, to develop the statistical tests, the statistical package Statgraphics 16 was used.

Results

Characteristics of manure of bovine origin

The initial characteristics of the manure of bovine origin before being used to generate the biomass in suspension in the SBR are presented in table 2.

Tabla 2. Parámetros físicos del estiércol de origen vacuno. Valores promedio y desviación estándar (DE) (*N* = 12).

Parámetro	***X***	**± *DE***	**Unidad**
Biomasa seca	72.3	6.2	%
Biomasa húmeda	27.7	6.2	%
pH	7.8	1.3	UpH
Materia volátil	0.15	0.05	kg Mv / kg estiércol

Fuente: Elaboración propia

Evaluation of control parameters and basic contaminants

The basic pollutants and control parameters of the SBR inlet water are presented in table 3. It is important to see that the characteristics of the wastewater to be treated fall within the average category according to the TSS concentration (220 mg / L- 1), and in the case of COD, it is in the medium-weak range (250-500 mg / L-1), as established by Tchobanoglous, Burton and Stensel (2003).

Tabla 3. Parámetros de control y contaminantes básicos del agua residual de entrada a los SBR. Valores promedio y desviación estándar (*N* = 18).

Parámetro	***X***	**± DE**
Turbiedad (UNT)	85.0	29.7
Color (UC)	986.0	132.9
pH	8.2	0.9
Temperatura (°C)	28.2	1.2
CE (µs/cm)	1480.1	205.5
OD (mg/L)	0.5	0.2
DQO (mg/L)	320.0	119.6
SST (mg/L)	227.1	83.5

Fuente: Elaboración propia

Table 4 shows the average results (± SD) of the influents and effluents in the different treatments in the SBR. The parameters analyzed as COD and SST show that the input wastewater in the three treatments has a medium wastewater characteristic (Tchobanoglous et al., 2003). Although these present load variability in the supply source like any domestic wastewater generating system.

Tabla 4. Comparación de parámetros de control y contaminantes básicos del agua residual a la entrada y salida de los SBR en cada tratamiento. Valores promedio y DE (*N = 18*)

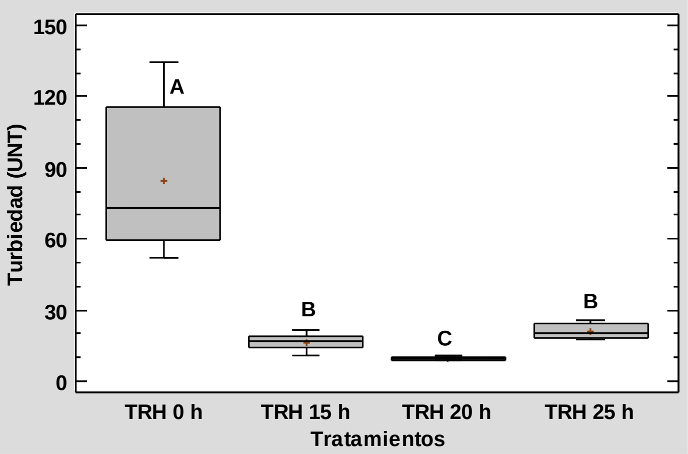
Parámetro	**TRH 15 h**				**TRH 20 h**				**TRH 25 h**			
	Inf.	**±*DE***	**Efl.**	**±*DE***	**Inf.**	**±*DE***	**Efl.**	**±*DE***	**Inf.**	**±*DE***	**Efl.**	**±*DE***
Turb. (UNT)	68.6	15.2	16.6	3.9	121.5	10.0	9.6	0.8	62.8	5.2	21.3	3.4
Color (UC)	1063.5	123.2	426.5	79.3	1014.3	101.0	291.4	34.5	870.3	87.4	442.2	102.0
pH	7.5	0.3	6.1	0.3	9.3	0.1	6.4	0.8	7.7	0.2	6.2	0.2
Temp. (˚C)	29.0	1.3	29.0	1.7	28.0	0.9	29.7	1.6	27.3	0.8	28.5	0.7
CE (µs/cm)	1304.7	232.7	964.5	102.5	1659.0	19.1	1075.2	102.1	1467.7	75.6	986.5	40.6
OD (mg/L)	0.6	0.1	3.2	0.6	0.3	0.1	4.3	0.4	0.6	0.1	3.9	0.1
DQO (mg/L)	259.4	57.4	62.9	14.5	465.9	37.7	35.4	3.0	226.7	33.0	80.4	12.9
SST (mg/L)	185.3	41.0	44.9	10.4	328.5	27.9	26.1	1.2	161.9	23.6	57.4	9.2

Fuente: Elaboración propia

Turbidity

The Kruskal-Wallis test evaluated the hypothesis that the turbidity medians (NTU) within each of the four treatment levels are equal; found that there is a statistically significant difference between the medians. Among the treatments, the one with the lowest median ± SD was the 20-hour HRT treatment with 9.2 ± 0.84 NTU, followed by 15-hour HRT with 16.9 ± 3.86 NTU and 25 HRT with 20.65 ± 3.41 NTU. HRT 0 h presented the highest mean value with 72.65 ± 29.02 NTU. It should be remembered that the latter is the inlet water (figure 3).

Figura 3. Valores de turbiedad en cada tratamiento. Contraste de medianas (mediana ± RI)



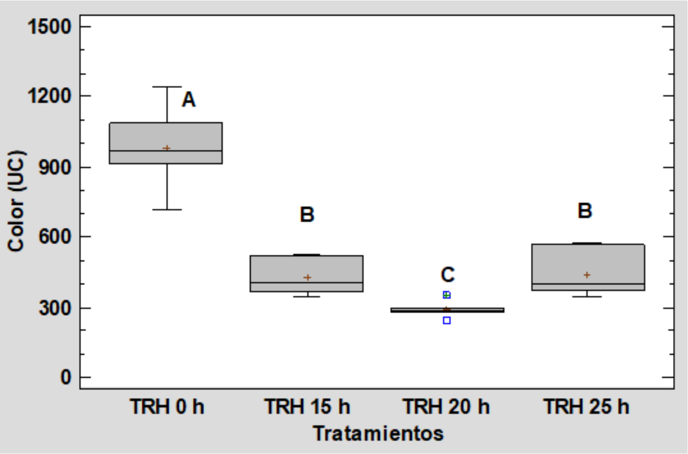
Nota: El tamaño de muestras compuestas es *N* = 18 para cada tratamiento. Letras diferentes representan diferencias estadísticamente significativas

Fuente: Elaboración propia

Color

The Kruskal-Wallis test for color (UC) shows that there is a statistically significant difference between the medians. The treatment with the lowest median value ± SD was HRT 20 h with 286.2 ± 34.53 CU, followed by HRT 25 h with 396.0 ± 102.02 CU and HRT 15 h with 402.5 ± 79.29 CU. The highest median value was HRT 0 h with 965.6 ± 129.72 UC, which is the input water in the experiments (figure 4).

Figura 4. Valores de color en cada tratamiento. Contraste de medianas (mediana ± RI)



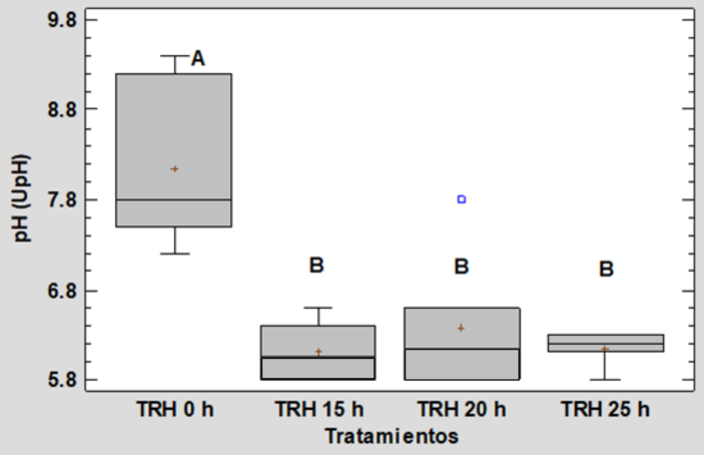
Nota: El tamaño de muestras compuestas es *N* = 18 para cada tratamiento. Letras diferentes representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

pH

The Kruskal-Wallis test for pH shows that there is a statistically significant difference between the medians. The treatment with the lowest median value ± SD was HRT 15 h with 6.05 ± 0.34 UpH, followed by HRT 20 h with 6.15 ± 0.77 UpH and TRH 25 h with 6.2 ± 0.19 UpH. The highest median value was HRT 0 h with 7.8 ± 0.85 UpH, which is the input water in the experiments (figure 5).

Figura 5. Valores de pH en cada tratamiento. Contraste de medianas (mediana ± RI)



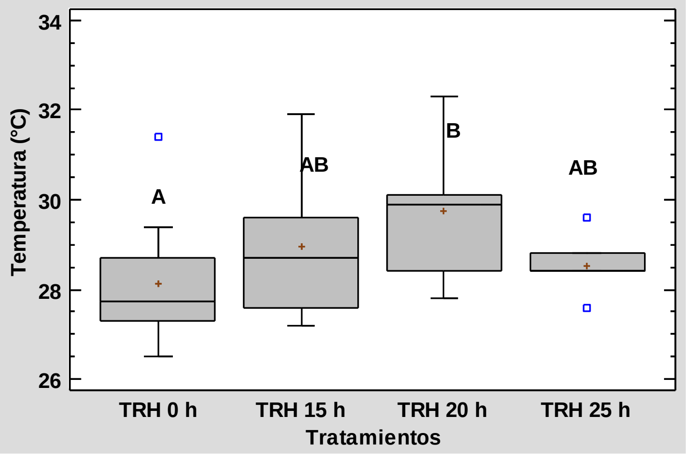
Nota: El tamaño de muestras compuestas es *N=18* para cada tratamiento. Letras diferentes representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Temperature

The Kruskal-Wallis test for temperature shows that there is a statistically significant difference between the medians. The treatment with the lowest median value ± SD was HRT 0 h with 27.75 ± 1.19 ° C, followed by HRT 25 h with 28.4 ± 0.65 ° C and HRT 15 h with 28.7 ± 1.69 ° C. The highest median value was HRT 30 h with 29.9 ± 1.57 ° C (Figure 6).

Figura 6. Valores de temperatura en cada tratamiento. Contraste de medianas (mediana ± RI)



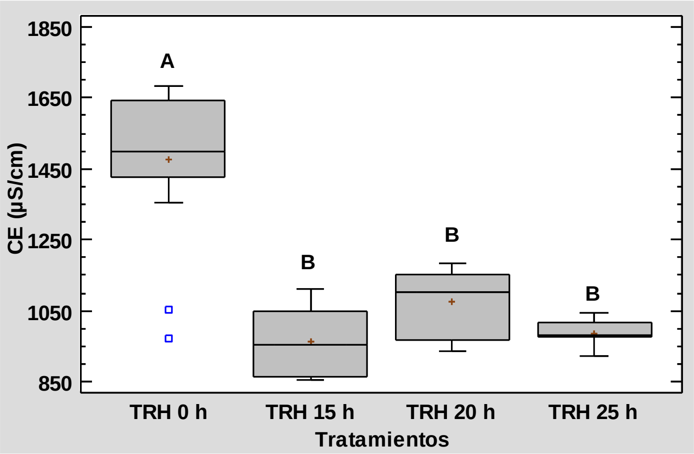
Nota: El tamaño de muestras compuestas es *N = 18* para cada tratamiento. Letras diferentes representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Electric conductivity

The Kruskal-Wallis test for CE shows that there is a statistically significant difference between the medians. The lowest median ± SD values were presented in the 15 hr TRH treatment (954.3 ± 102.55 µS / cm), followed by 25 hr TRH (980.35 ± 40.59 µS / cm), 20 hr TRH (1103.35 ± 102.1 µS / cm) and the highest median value was HRT 0 h with 1500.5 ± 199.78 µS / cm (Figure 7).

Figura 7. Valores de CE en cada tratamiento. Contraste de medianas (mediana ± RI)



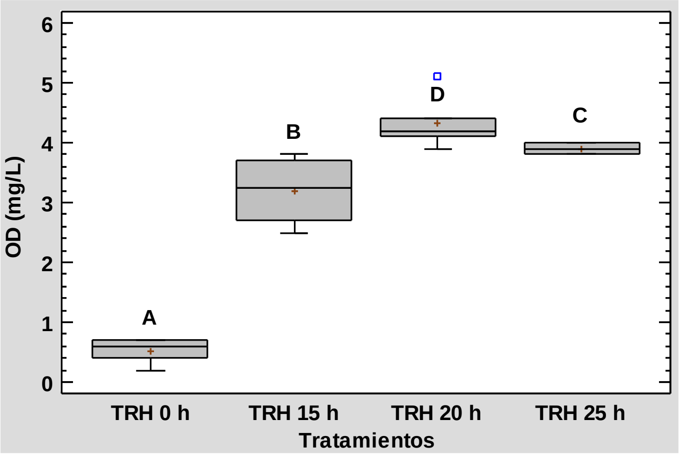
Nota: El tamaño de muestras compuestas es *N* = *18* para cada tratamiento. Letras diferentes representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Dissolved oxygen

The Kruskal-Wallis test for OD shows that there is a statistically significant difference between the medians. The lowest median ± SD values were presented in the 0 h HRT treatment (0.6 ± 0.17 mg / L), followed by 15 h HRT (3.25 ± 0.59 mg / L), 25 h HRT (3.9 ± 0.09 mg / L) and the highest median value was HRT 20 h with 4.2 ± 0.42 mg / L (Figure 8).

Figura 8. Valores de OD en cada tratamiento. Contraste de medianas (mediana ± RI)



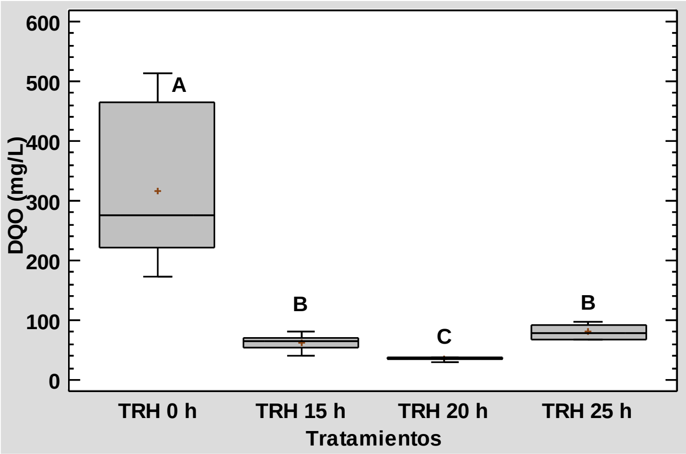
Nota: El tamaño de muestras compuestas es *N* = *18* para cada tratamiento. Letras diferentes representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Chemical oxygen demand

The one-way Kruskal Wallis analysis shows the existence of a statistically significant difference between the medians of the COD variable of the evaluated treatments. The lowest median ± SD values were presented in the 20-hour TRH treatment (35.6 ± 2.98 mg / L), followed by 15-hour TRH (63.9 ± 14.54 mg / L), 25-hour TRH (78.05 ± 12.91 mg / L) and the highest median value was HRT 0 h with 274.75 ± 116.56 mg / L, which is the input water to the treatments (figure 9).

Figura 9. Valores de DQO en cada tratamiento. Contraste de medianas (mediana ± RI).



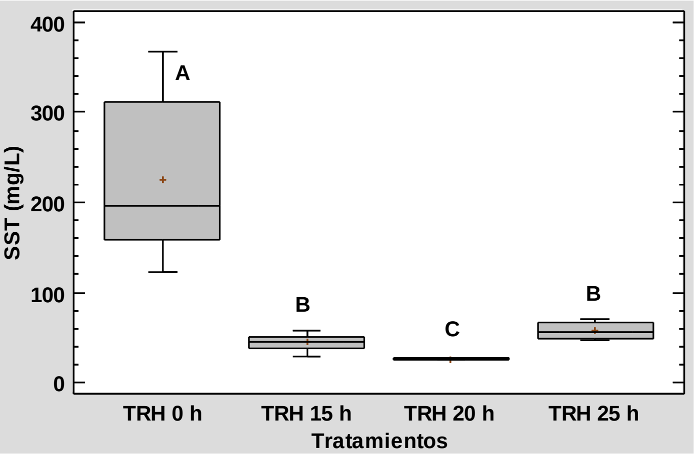
Nota: El tamaño de muestras compuestas es *N = 18* para cada tratamiento. Letras diferentes representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Total suspended solids

The one-way Kruskal Wallis analysis shows the existence of a statistically significant difference between the SST medians of the different treatments evaluated. The lowest median ± SD values were presented in the 20-hour TRH treatment (26.35 ± 1.20 mg / L), followed by 15-hour TRH (45.65 ± 10.38 mg / L), 25-hour TRH (55.8 ± 9.24 mg / L) and the highest median value was HRT 0 h with 196.25 ± 81.43 mg / L, which is the input water to the treatments (figure 10).

Figura 10. Valores de SST en cada tratamiento. Contraste de medianas (mediana ± RI)



Nota: El tamaño de muestras compuestas es *N* = *36* para cada tratamiento. Letras diferentes representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Operating conditions and removal efficiencies of treatments in the SBR

The operating conditions in each of the treatments show different behaviors. The best treatment was elicited in the experiment with 20 hours of TRH, which presented 2220 ± 93.6 mg / L of SSVLM, an IVL 169.8 ± 18.5 ml / g and a K of 20.8 h-1. The other parameters and conditions of the experiments are presented in Table 5. The concentration of SSVLM is double that reported in other studies with activated sludge that use around 1071 mg / L (Flores, Cuevas and González, 2019), but it is lower than that reported in the industrial wastewater treatment of Amorim et al. (2016). The volumetric index of the mud (IVL) is within the moderate range in compaction and sedimentation characteristics of the mud (Ferrara y Ramírez, 2013).

Tabla 5. Condiciones de operación del SBR bajo diferentes TRH. (*N=18*).

Parámetro	TRH-15 h		TRH-20 h		TRH-25 h	
	X	**± *DE***	***X***	**± *DE***	***X***	**± *DE***
SSVLM (mg/L)	2,169.4	162.8	2,220.0	93.6	2,208.2	106.4
DQO influente (mg/L)	247.6	57.4	229.1	21.0	217.7	33.0
DQO efluente (mg/L)	61.1	14.5	35.2	3.0	81.7	12.9
q, *n* = 1 (h^{-1} L mg^{-1})	1.3	0.3	1.6	0.2	1.5	0.4
K (h^{-1})	45.5		20.8		47.0	
IVL (ml/g)	152.4	12.7	169.8	18.5	77.3	12.4

Fuente: Elaboración propia

Finally, the removal efficiencies of the water quality process control parameters show that the 20 h TRH treatment presented the highest efficiency with 92.1% for turbidity, 71.3% for color, 31.2% for pH, -6.1% for temperature, 35.2% for CE, -1371.6% for DO, 92.4% for COD and 92% for SST. It is important to clarify that the negative sign (-) in the removal efficiency indicates that the value of the parameter is higher at the output and is lower at the input, important for the case of temperature, which shows us the increase in this value in the effluent, and in the case of DO there is a higher concentration in the effluent as a product of aeration in the process. The efficiency of the different treatments is presented in table 6.

Tabla 6. Eficiencias de remoción de contaminantes básicos del SBR operado bajo diferentes TRH (*N* = 18)

Parámetro	TRH 15 h	TRH 20 h	TRH 25 h
	ER (%)	**ER (%)**	**ER (%)**
Turbiedad (UNT)	75.8	92.1	66.2
Color (UC)	59.9	71.3	49.2
pH	18.4	31.2	19.8
Temperatura (^{0}C)	0.2	-6.1	-4.5
CE (µS/cm)	26.1	35.2	32.8
OD (mg/L)	-413.4	-1371.6	-522.3
DQO (mg/L)	75.8	92.4	64.5
SST (mg/L)	75.8	92.0	64.5

Fuente: Elaboración propia

Discussion

Turbidity and color

Color and turbidity are quickly determined parameters for process control in wastewater treatment systems. They are related to the presence of suspended solids in wastewater (Ortiz, López, Torres and Pampillón, 2018). High turbidity values in the effluent indicate high concentrations of suspended solids (after sedimentation) and is an obvious indication of the malfunction of the system (Conagua, 2016). During the experimental phase, the 20 h SBR TRH presented the lowest values (mean ± SD) of color and turbidity with 9.6 ± 0.8 NTU and 291.4 ± 34.5 UC; the maximum value was presented in HRT 25 h with 21.3 ± 3.4 NTU and 442.2 ± 102.0 UC. The removal efficiency for TRH 20 h was 92.1% in turbidity and 71.3% in color; while the 15 h TRH reached 75.8% turbidity and 59.9% color. The 25 h TRH treatment achieved a removal efficiency of 66.2% for turbidity and 49.2% for color.

Carrasquero et al. (2014) treated slaughterhouse wastewater in a SBR and reported that 10 and 12 hour HRT are sufficient to reach 73% (influent 2875 UC-effluent 781 UC) and 91% (influent 4125 UC-effluent 344 UC) of color respectively; for turbidity, 85% (influent 232 NTU-effluent 25 NTU) and 77% (influent 99 NTU-effluent 23 NTU) were removed respectively, which shows that there are no significant differences between the treatments (10 and 12 h) with $p \leq 0.05$. In our case, for turbidity and color there is a statistical difference ($p <0.05$) between the three treatments (0, 15, 20 and 25 hours); the 20 h HRT is the most efficient as it achieved the lowest concentration.

pH

The optimal pH range to ensure the activity and development of microorganisms in the SBR is between 6.0 and 8.5 units, values in which the wastewater to be treated and the system in the aeration tank must be, as it favors the processes of degradation of organic matter, nitrification and denitrification (Conagua, 2016). This interval is similar to the discharge criteria established by NOM-001-SEMARNAT-1996 (6.5 to 10 units) and in the effluents of this study a range of 6.1 to 6.4 units was presented. A change of the pH to the established one can generate an impact in all the biota and although the bacteria can survive between 5.0 and 10.0 units they will not be able to reproduce, which causes that the microorganisms die, and if the pH is below 6.5, the fungi will predominate on bacteria and there will be a low removal of BOD and poor sedimentation (Conagua, 2016). The results in this study for pH, although they are slightly below the range established by NOM-001-SEMARNAT-1996, are within the range established in the Conagua manual (2016) for optimal activated sludge processes (or their variants) and there is no significant difference ($p < 0.05$) in the pH variable between the three HRTs (15, 20 and 25 h); here the different one is HRT 0 h.

Temperature

Temperature is an important operating parameter of SBRs because it has a direct effect on bacterial activity and because operationally there is no control over it. The optimal range for aerobic bacterial activity is between 25 and 32 ° C. With high temperatures the bacteria become more active; and at low temperatures, less active. However, above 35 ° C the enzymes are destroyed, which results in a low efficiency of pollutant removal in the process (Conagua, 2016). This parameter is regulated for discharge by NOM-001-SEMARNAT-1996, which establishes a maximum permissible limit of 40 ° C for certain receiving bodies, a temperature that was not reached throughout the evaluation process, since in the influent the range was from 27 to 29 ° C, while in the treatment effluent there was a range of 28.5 to 29.7 ° C. The results presented in the experiment are good, since the residual water temperature did not exceed 35 ° C nor was it less than 15 ° C, conditions that the plants must have in their operation, since this guarantees the presence of mesophilic bacteria (Carrasquero , Rodríguez, Bernal and Díaz, 2018). In this case, there is no statistically significant difference ($p \geq 0.05$) in the temperature variable, but the 20 h HRT is efficient for the development of microorganisms.

Electric conductivity

The electrical conductivity of water is the ability to transport electrical current by the ions present in it. The increase in ion concentration causes an increase in conductivity (Crites and Tchobanoglous, 2000). This parameter is important to measure to see the possibility of reuse of treated water in irrigation. If the irrigation water has an electrical conductivity (EC) lower than 0.7 dS / m (<700 µS / cm), it will be possible to irrigate almost all crops, except those very sensitive to salts; but if the EC is in the range of 0.7 to 3.0 dS / m (700 to 3000 µS / cm), it is only recommended to sow those crops that have good to moderate tolerance to salinity (Cisneros and Saucedo, 2016). In our case, the treatments presented effluents in the range of 964.5 µS / cm to 1075.2 µS / cm: in degree of restriction for its use from light to moderate as established by the Food and Agriculture Organization (FAO) (Ayers and Westcot, 1994). We can see that there is no significant difference in the CE variable between the three HRTs (15, 20 and 20 h) ($p < 0.05$); different is the inlet water, which was evaluated as a treatment in the experiment.

Dissolved oxygen

The DO in the SBR is very important to the operation. If the DO is very low, microbial activity and low organic matter removal are inhibited; If the DO increases, it may be due to a high mortality of microorganisms, and a sudden drop in DO indicates that a large amount of organic matter entered the system, so it is recommended to have a residual DO of one to two mg / L in the aerator (Araya et al., 2014; Conagua, 2016). In our experiments, the SBRs operated with a DO concentration of four to six mg / L-1, as recommended for municipal wastewater treatment and for some industrial waters (Carrasquero et al., 2018; Zhang, Jiang, Xu , Wang, Xie, 2017). The inlet water to the SBRs presented low DO values, as it acquired septic characteristics due to the temperature (32 ° C ambient) and TRH in the campus cistern (45 minutes). High DO concentrations can adversely affect sedimentation, as the mixture can break down flocs. Sludge with swelling is the result of wastewater treated in a process lacking in oxygen or nutrients, which is associated with the presence of filamentous microorganisms (Pacheco, Jáuregui, Pavón and Mejía, 2003). However, in our case, the DO concentration in the effluent was found in a range of 3.2 to 4.3 mg / L, and showed differences ($p < 0.05$) between the treatments; HRT 20 h was optimal with a median of 4.2 mg / L.

Chemical oxygen demand

COD is a parameter that is increasingly used, since its analysis is much faster than that of BOD and allows us to determine non-putrescible inorganic and organic matter, susceptible to being chemically oxidized by dichromate in an acid medium; It also allows evaluating the efficiency of a plant in less time, which is vital in decision-making (Crites and Tchobanoglous, 2000). Taking into account the above, Carrasquero et al. (2018) evaluated the efficiency of a sequential biological reactor in the treatment of effluents from a meat products processing plant, with three different HRT (7, 10 and 12 h) and the COD variable as the main parameter in the process control. The influent presented a variation between 1234 to 1825 mg / L, the treatments reached 92.6% (7 h), 91.9% (10 h) and 91.3% (12 h) of COD removal efficiency and no significant differences were found between the three times evaluated ($p \leq 0.05$). Although in our study the wastewater is of a domestic nature, the removal efficiencies for QDO for the best treatment are similar to those of Carrasquero et al., (2018), since the experiment with HRT 15 h obtained 75.8%, HRT 20 h with 92.4% and TRH 25 with 64.5%.

It is important to highlight that in a treatment system it is more difficult to achieve high removal efficiencies of a pollutant when the influent has low concentrations or medium-weak water quality (Tchobanoglous et al., 2003). Domestic wastewater presents a greater amount of substances than in a slaughterhouse and the SBR is not applicable to all types of organic effluent, the presence of toxic compounds can negatively affect the performance of this type of treatment (Martínez, Calderón and Ruiz, 2017) . This is demonstrated by Nava, Gasperín and Durán (2014), who treated wastewater from a refinery in a SBR whose input concentration was 487 ± 42 mg / L, and obtained an effluent of 119 ± 30 mg / L, which represents a COD removal of 75%, due to the presence of phenols. Finally, the draft standard PROY-NOM-001-SEMARNAT-2017 (Semarnat, January 5, 2018) sets the discharge limit to marine areas and estuaries at 85 mg / L of COD, a value that the three evaluated treatments satisfactorily met.

Total suspended solids

The behavior of the influent for the SST parameter presented a variability of 162 to 328 mg / L, typical concentration of a wastewater with domestic characteristics. The best treatment was presented in the TRH 20 h with an average effluent of 26.1 ± 1.2 mg / L, which allowed it to reach a removal efficiency of 92% of SST and to meet the discharge criteria for protection of aquatic life, which allows to download 40 mg / L (NOM-001-SEMARNAT-1996); the other treatments are above this concentration. Derlon, Wagner, Ribeiro da Costa and Morgenroth (2016) evaluated the formation of aerobic granules in the treatment of low resistance municipal wastewater using a sequential batch reactor at constant volume, and reported (influent 140 ± 30 mg / L) that They were able to reduce the concentration of their effluent to concentrations lower than 10 mg / L of TSS, by making a selective use of organic carbon during anaerobic feeding.

Conclusion

The active biomass of cattle in the treatment of domestic wastewater in SBR is efficient in the removal of basic pollutants and control parameters of domestic wastewater and favors operating times and costs.

Experiments show that it is possible to use a 20 hour HRT with wastewater with medium load characteristics to achieve efficiencies of 92% in COD removal. Increasing the retention time decreases the removal of this parameter.

Adequate aeration (four to six mg / L of DO) must be guaranteed in the system to avoid the low removal of pollutants due to the increase of filamentous microorganisms, which causes an increase in TSS in the effluent.

Finally, we can recommend the implementation of the use of SBRs for the treatment of domestic effluents in decentralized systems in the southeast of Mexico as a viable alternative in the treatment of their wastewater.

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