INGENIERIA SANITARIA Y AMBIENTAL

Determinación de los coeficientes biocinéticos de un sistema aerobio para remoción de almidón de papa

SANITARY AND ENVIRONMENTAL ENGINEERING

Determination of biokinetic coefficients of an aerobic system for potato starch removal

Yudy Andrea Londoño-Cañas, [1] Paola Rodriguez-Saldarriaga[1], Jennifer Arcila-Sáenz [1], Gustavo A. Peñuela[§] [1]

[1] GDCON Research Group, Faculty of Engineering, University Research Headquarters (SIU), University of Antioquia, Street 70 # 52-21, Medellín, Colombia

yudy.londono@udea.edu.co, paola.rodriguezs@udea.edu.co, jennifer.arcila@udea.edu.co, gustavo.penuela@udea.edu.co

Londoño-Cañas YA, Rodríguez-Saldarriaga P, Arcila-Sáenz J, Peñuela GA. Determinación de los coeficientes biocinéticos de un sistema aerobio para remoción de almidón de papa. Ingeniería y Competitividad, 2023, 25(1); e-21812109. https://doi.org/10.25100/iyc.v25i1.12109

Recibido: 28 de agosto de 2022 – **Aceptado:** 03 de octubre de 2022

Abstract

This study presents the performance of a laboratory scale completely mixed aerobic reactor for starch wastewater treatment. The reactor was operated for 119 days, divided into 5 operational phases which included the start-up and the variation of cell-residence time. In order to determine the biokinetic coefficients for starch removal, the cell-residence time was varied between 20 to 4 days, and the system operation was set to a hydraulic retention time of 24 hours with a completely mixed reactor setup. The chemical oxygen demand concentration was 1000mg/L in the inflow of the reactor and dissolved oxygen remained above 2mg/L.

In this experimentation time, the parameters such as pH, chemical oxygen demand (in the influent and effluent), dissolved oxygen and mixed liquor suspended solids were monitored. The calculation of biokinetic constants was done by an approximate method, using the graphical Lineweaver-Burk method. The biokinetic coefficients determined were for maximum substrate removal rate (k_0), half saturation rate constant or affinity constant (k_m), sludge yield coefficient (Y), and microbial decay or indigenous respiration rate (k_e).

The results showed that Y, (k_0), and (k_m), were in the range of 0.3- 0.7 $mgSSV/mgBOD_5$, 2- 8 day^1 and 40-120 mg/L (COD- BOD_5), respectively. Values of the coefficients were within the range of those reported for conventional activated sludge processes.

Keywords: Biological processes; Bioremediation; Starch removal; Water treatment;

Resumen

Este estudio presenta el rendimiento de un reactor aerobio completamente mezclado, a escala de laboratorio, para el tratamiento de aguas residuales provenientes de la extracción de almidón de papa. El reactor se operó durante 119 días divididos en 5 fases de operación que incluyeron la puesta en marcha y la variación del tiempo de retención celular. Con el fin de determinar los coeficientes biocinéticos, el tiempo de retención celular se varió entre 20 y 4 días, y el funcionamiento del sistema se estableció con tiempo de retención hidráulica de 24 horas a una configuración hidráulica de mezcla completa. La concentración de demanda química de oxígeno fue de 1000 mg/ en la entrada del reactor y el oxígeno disuelto permaneció por encima de 2 mg/L.

En este tiempo de experimentación se monitorearon parámetros como pH, demanda química de oxígeno (en el afluente y efluente), oxígeno disuelto y sólidos suspendidos del licor de mezcla. El cálculo de las constantes biocinéticas se realizó mediante un método aproximado, utilizando el método gráfico Lineweaver-Burk. Los coeficientes biocinéticos determinados fueron: La tasa máxima de remoción de sustrato (k_0), la tasa media de saturación o constante de afinidad (k_m), el coeficiente de rendimiento de lodo (Y) y la tasa de respiración endógena (k_e).

Los resultados mostraron que Y, (k_0), y (k_m), estuvieron en un rango de 0,3- 0,7 mgSSV/mgBOD5, 2- 8 1/día y 40-120 mg/L (COD- BOD5), respectivamente. Estos valores de los coeficientes estuvieron en el rango de los coeficientes reportados en la literatura en el tratamiento convencional de lodos activados empleados para el tratamiento de residual doméstica.

Palabras clave: Biotecnología; Bioremediación; Remoción de almidón; Tratamiento de agua.

Nomenclature

COD	Chemical oxygen demand (mg COD/L)	Θc	Cell-residence time (day)
BOD	Biochemical oxygen demand (mg BOD/L)	μ_{max}	Maximum specific growth rate (mgVSS/mg CODday)
CMAS	Completely mixed activated sludge	μ	Specific growth rate (mgVSS/ mgCODday)
X	Mixed liquor suspended solids (mgVSS/L)	V	Reactor useful volume (m^3)
Q	Flow (L/s o m3/day)	Q_w	Reactor outflow
HRT	Hydraulic retention time (hours)	Q_r	Reactor internal recirculation flow
SVI	Sludge volumetric Index	F_0	Inffluent COD concentration (mgCOD/L)
VSS	Volatile suspended solids (mg VSS/L)	F	Concentration of growth-limiting substrate (mgCOD/L)
TSS	Total suspended solids (mg TSS/L)	k_0	Maximum substrate removal rate ($k_0 = \mu_{max}$ /Y) (mgCOD/mgVSS day)
k_m	Half saturation rate constant (mgCOD/L)	k_e	Microbial decay or indigenous respiration rate (1/day)
Y	Yield coefficient (mgVSS/mgCOD)	OCR	Oxygen consumption rate gO2/gSSVday)

1 INTRODUCTION

Surface water pollution is a serious problem for many developing countries. The main causes are industrial and domestic wastewater discharges that contain excessive concentrations of nitrogen, phosphorous, and organic pollutants into natural waters such as rivers and lakes (1). Unfortunately, one source of this type of pollution are starch factories, which are classified as polluting industries around the world (2). In Latin America, this issue is especially problematic due to the lack or low efficiency of wastewater plants to treat general wastewater. In many cases, this raw wastewater is discharged directly into natural water.

The potato represents one of the most important crops for the food sustenance of the world population but, at the same time, it is useful for diverse industrial processes and starch production. This starch is used as an industrial raw material in food, textile, chemical, medicines, and others(2,3). However, the starch production process requires a huge amount of water for to wash the feedstocks, perform the starch extraction process, and clean the pipelines and instruments. Most of the water that is used in the process is converted into wastewater (2). It is estimated that production each ton of starch will generate between 10-20 m^3 wastewater discharge(3), containing organic products such as starch, proteins, amino acids sugars, and potassium (4).

The main concern arising due to this kind of process is that wastewater discharges from starch factories usually have a high organic load, which causes a drastic decrease in the amount of oxygen dissolved in natural water resources (2). Usually, wastewater from starch production contains chemical oxygen demand (COD) concentrations between 5000 and 50000 mg/L, biochemical oxygen demand concentration between 3000 and 30000 mg/L, and suspended solids concentration between 1000 and 5000 mg/L(3). Therefore, effective treatment of the starchy wastewater is critical.

Different kinds of processes can be used to treat wastewater from starch production. Both physicochemical and biological technologies can present good efficiencies. However, the biological process has gained a lot of attention in the last few years. Some reasons for this are that these processes present good efficiencies with low operation costs, and are sustainable and environmentally friendly technologies.

The aerobic process is a biological wastewater technology that has shown good efficiencies in the removal of conventional organic pollutants as determined by values such as chemical oxygen demand, biological oxygen demand, and nutrients in the typical concentrations of domestic wastewater affluents. Therefore, this process has been a focus in the treatment of domestic wastewater. However, biokinetic coefficients vary between different types of wastewaters. Table 1 shows the typical biokinetic coefficients values for activated sludge.

Table 1. Typical biokinetic coefficients values for activated sludge

Description	**Coefficient**	**Units**	**Value**	
			Range	**Typical**
Maximum specific rate of substrate removal	k_0	Day -1	2-8	4
Endogenous respiration coefficient	ke	Day $^{-1}$	0.03-0.07	0.05
Saturation coefficient	Km	mg/L (COD- BOD_5)	40-120	80
Performance coefficient	Y	mgSSV/mgBOD_5	0.3-0.7	40

Source: Von Sperling and C. A. Chernicharo, 2005 (5), M. & E. Inc et al (6)

The biological process can be a potential tool to treat industrial wastewaters with specific characteristics, but the biokinetic coefficients (kinetic and stoichiometric coefficients) must be determined to optimize the scale applications of the process. The purpose of this study was to use an aerobic semi continuous reactor to determine the biological coefficients to treat wastewater from starch production and to evaluate the efficiencies of this process in the removal of a high concentration of potato starch.

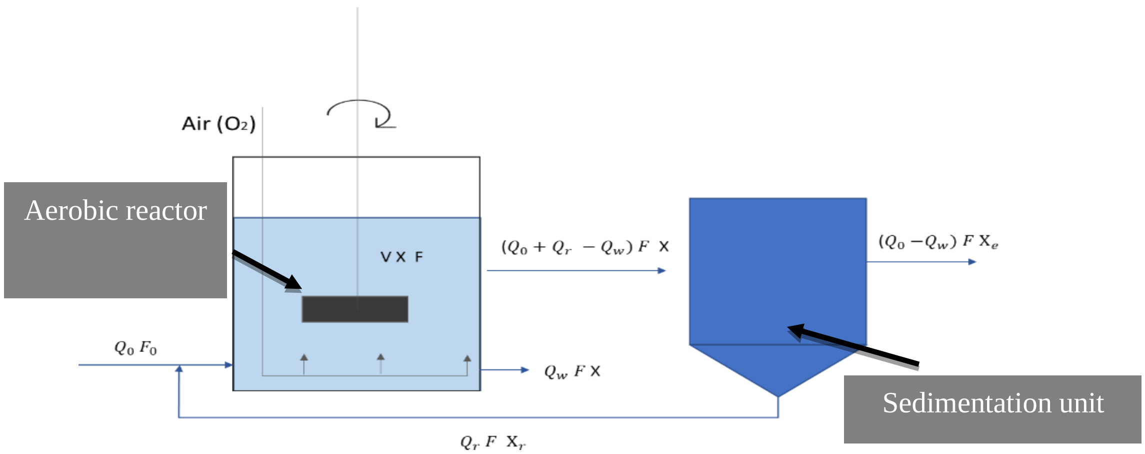
2 MATERIALS AND METHODS

2.1 Experimental setup and operation

The aerobic reactor used in this study was constructed in acrylic with an effective volume of 4.0 L, overall height of 30 cm, and inner diameter of 15 cm. The system had quick-closing half-inch valves; one of these was located at the bottom of the reactor and enabled entry of the wastewater flow, while the other two facilitated the blowdown of the sludge. The incoming flow enterered using a peristaltic pump with a capacity of 6–600 RPM.

The reactor was completely mixed by a mechanical stirrer, and air was supplied by a fish tank pump through a plastic pipe in which stones were placed to generate fine air bubbles. This facilitated the transfer of oxygen to the microorganisms. The biomass used was of the suspended type. The schematic diagram of the reactor is given in figure 1.

Figure 1. Schematic representation of the aerobic system used during the experimentation (check the nomenclature part).



Source: Authors own creation.

The reactor worked in a semicontinuous configuration; therefore, the system's air supply, agitation, and peristaltic pump were activated with a digital timer for the different periods. The reactor worked for a total of 16 active hours and 8 inactive hours every day. The effluent from the system was collected in a sedimentation unit, where it was subsequently returned to the reactor. The purge was carried out directly from the aeration tank according to the age of the sludge from the experimental phase.

2.2 Inoculum

The system was inoculated with an aerobic sludge from a domestic wastewater treatment plant, called Aguas Claras, located in the municipality of Bello, Antioquia. The sludge presented good sedimentation characteristics and a low sludge volumetric index.

2.3 Composition of synthetic wastewater

Synthetic wastewater was prepared to simulate industrial wastewater from the potato starch extraction process. The concentrations of COD used were 500 and 1000 mg / L. The macro and micronutrients were added according to what was reported by Molina (7) for aerobic systems. The pH in the reactor was controlled by adding sodium bicarbonate into the incoming flow.

2.4 Operational Strategy

The reactor was operated for 126 days through 5 phases of operation that consisted of start-up and acclimatization and four subsequent phases which evaluated the variation of the sludge retention time (sludge age). Throughout the study, the kinetic and stoichiometric coefficients were determined, varying the sludge retention time between 20, 10, 8, and 4 days. The biomass concentration varied between 3040 and 610 mg/L and the F/M ratio varied between 0.36 and 1.70 1.92 gCOD / gVSS·d. Table 2.1 presents a summary of the experimental conditions used for the operation of the system

.***Table* 2**. Operational strategy

Phases	Period (days)	HRT (hours)	θ_c (days)	COD (mg/L)
1	1-66	24	variable	500
2	67-82	24	20	1000
3	83-94	24	10	1000
4	95-107	24	8	1000
5	108-119	24	4	1000

Source: Authors own creation.

2.5 Analytical methods

Tests for COD, TSS, VSS, and SVI were done in the laboratory of the research group known as the Pollution Control and Diagnostics Group (GDCON), at the University of Antioquia, following protocols established in the Standard Methods (8). The GDCON laboratory is accredited by the Environmental Research Institute under the Ministry of Environment of Colombia (IDEAM) to carry out these analyses.

2.6 Aerobic biokinetic coefficients determination

The interaction between the growth of microorganisms and utilization of the growth-limiting substrate in a completely mixed activated sludge is based on the Monod model (9). This model is the most commonly used one for determining the biokinetic coefficients in biological processes, which can be expressed as (10):

$$\mu = \frac{\mu_{max} \cdot F}{K_m + F} \quad \text{Eq. (1)}$$

μ_{max} is the maximum specific growth rate and K_m is the saturation constant, which is numerically equal to the substrate concentration when $\mu = 0.5\mu_{max}$. The coefficients were determined based on the following assumptions:

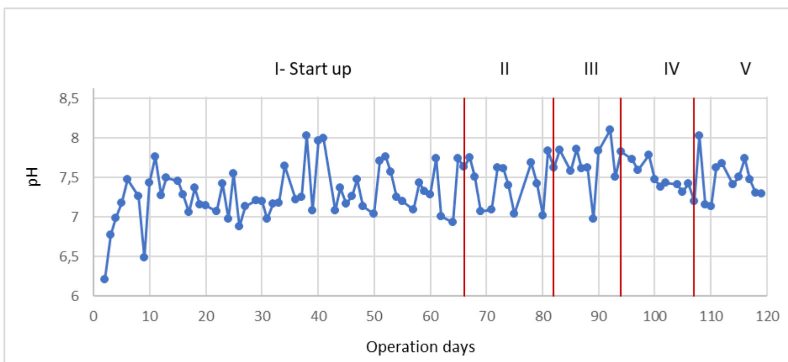
i. The reactor volume is constant and completely mixed.
ii. Influent COD concentration remains constant.
iii. The synthetic influent wastewater does not contain microbial solids.
iv. Steady-state conditions prevail throughout the system during the experimentation time.

According to figure 1, the mass balance equations of both the biomass and substrate removal can be described by the following equations (11):

3 RESULTS AND DISCUSSION

The aerobic reactor used in the experimentation was operated under mesophilic conditions. The pH parameter (Table 2) was monitored every day to keep good environmental conditions for the microorganisms. The dissolved oxygen was always over 2 mg/L.

Figure 2. Behavior of the pH during the experimental time.



Source: Authors own creation.

Potato starch could be a good carbon source when used as a substrate for biomass. However, the low water solubility and high potato starch concentrations in industrial wastewater may be a limiting factor for the aerobic process. Table 2 shows the pH variation through the experimentation time. The values show a tendency to remain between 7 and 8. The pH was controlled by adding 0.5 g of sodium bicarbonate. According to the literature, the pH in this biological process can vary while remaining close to neutrality. However, the pH in wastewater can fluctuate in the range of 6.5-8.5 (16), which means that the environmental medium was suitable for the metabolic development of most microorganisms

.

Table 3. Reactor performance under start-up and steady-state conditions at four different Ɵc.

Parameter	Start up	Sludge retention time (days) 20	10	8	4
Operation period (days)	01-66	67-82	83-94	95-107	108-119
F/M ratio (mg CODmg/VSS day)		0.36	0.48	1.11	1.7

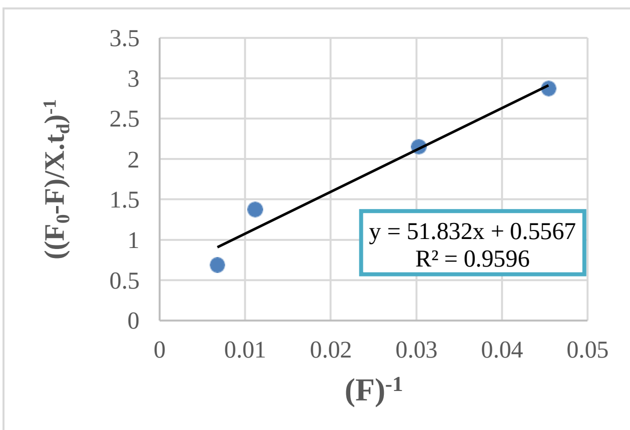
pH	7.3 ± 0,3	7.4 ± 0.3	7.7 ± 0.3	7.5 ± 0.2	7.5 ± 0.3
Afluent COD (mg/L)	478 ± 52	1081 ± 71	1074 ± 85	1108 ± 115	1038 ± 74
Effluent COD (mg/L)	69 ± 20	22 ± 4	33 ± 5	90 ± 8	148 ± 11
COD removal efficiencies (%)	86 ± 4	95 ± 1	94 ± 1	94 ± 2	92 ± 2

Source: Authors own creation.

The sludge retention time was used as a controlling parameter throughout the experimentation. The reactor was operated applying different Ɵc (Table 1). Therefore, the biomass concentration (mixed liquor suspended solids -MLSS) was changed for phases from 2 to 5 with average values of 3040, 2240, 1400 610 mgSS/L respectively. The biokinetic coefficients were determined at steady-state, a condition that was assumed to exist when biomass growth and COD removal were constant.

The biokinetic coefficient values were estimated through regression analysis of experimental data using the Lineweaver-Burk method as shown in figure 3. The values obtained for k_0 and k_m were 1.8 1/day and 93 mg/L COD respectively. The graphic analysis of data shows a high regression coefficient with an R^2 of 0.9596.

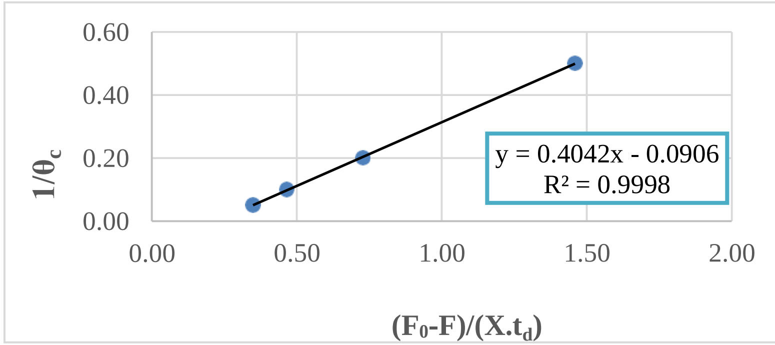
Figure 3. Lineweaver-Burk method for COD removal



Source: Authors own creation.

In the same way, the Y and k_e coefficients were estimated through the graphical analysis of experimental data, as shown in figure 4. The Y and k_e values obtained were 0.4 mgSSV/mgCOD and 0.09 1/day respectively. In this case, the graphic analysis of data shows a good fit with a regression coefficient where the R^2 was 0.9998.

Figure 4. Determination of Y and k_e

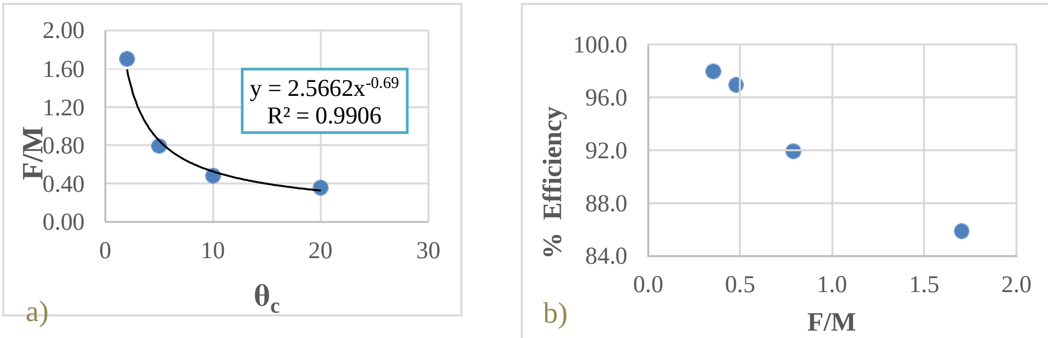


Source: Authors own creation.

It is important to mention that the biokinetics coefficient values obtained for starch removal are similar to those for domestic wastewater reported in table 1. The constant k_m represents the affinity of the biomass for the substrate. In this case, the high values of this constant mean a high affinity of the microorganisms for the starch. This could be because starch is a highly biodegradable substrate, and the reactor had a good performance at the COD concentration of 1000 mg/L. However, the reactor was operated at a high HRT (24 hours), which means that if the COD load changes the starch removal efficiency could change as well (17). A study on starch wastewater treatment reported by Wang and collaborators (1) showed that aerobic system efficiency is affected by HRT. They proved that at high HRT, such as 24 hours, the reactor had efficiencies up to 96.5% but when the HRT was low (HRT = 6 hours) the efficiencies decreased considerably.

Figure 5 shows the behavior of the F/M ratio vs Ɵc. The F/M ratio decreases when Ɵc is higher and vice versa. Therefore, this graph describes the way the F/M ratio changes with the Ɵc variation through the experimentation time. It is important to note that the reactor had a strong variation in biomass concentration (mixed liquor suspended solids) under the effect of Ɵc decrease and, as a consequence, the ratio of F/M rose considerably during the experimentation time, as can be seen in figure 5.

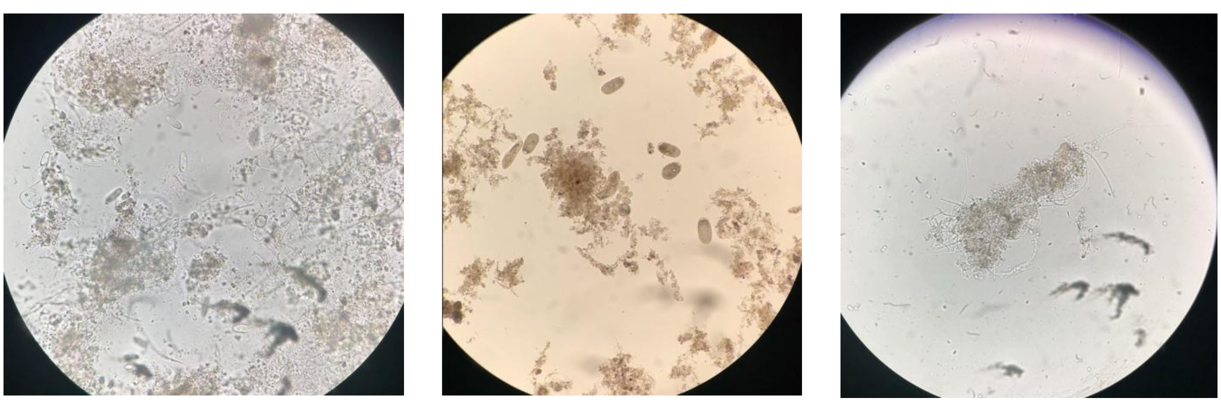
Figure 5. Graphic representation of a) the behavior of F/M vs the variation in the Ɵc. b) variation of system efficiency vs the variation in the Ɵc



Source: Authors own creation.

On the other hand, the efficiency of the system is strongly affected by the F/M ratio. When the F/M ratio is lower the efficiency of the system increases. This good efficiency in the system occurs because, when the ratio F/M is lower, the biomass is in high competition for the substrate, which may not be enough for the microorganism. Therefore, there is higher efficiency in the system. However, it is important to note that the system dynamics can change if the cell residence time is too high. At a low F/M ratio the presence of nematodes and rotifers predominates, but if the cell-residence time continues to increase, the biomass decreases to the point that is not possible to find active cells through microscopic observation (figure 6 c). In this case, system efficiency decreases dramatically. Therefore, when determining biokinetic coefficients, the system never reached this critical condition. The reactor was operated under a steady-state with active biomass.

Figure 6. Change in the microbial structure under the effect of ration F/M variation

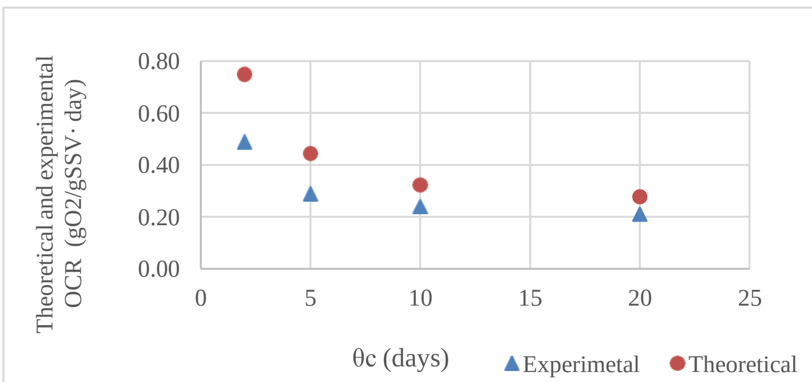


(Source: own elaboration).

However, when the F/M ratio increases, the system efficiency decreases (figure 5b). This drop-in efficiency is associated with low concentration of the biomass, despite its greater biological activity. In this case, there is a change in the sludge microbial structure whereby dispersed bacterial populations, free ciliates, and flagellates predominate (figure 6 a-c).

These changes in the biological structure also affect the system's operation. When the F/M ratio is lower, the SVI is good, and the sludge has good sedimentation characteristics with SVI values below 100 mL/g (7). However, when the F/M ratio is higher the SVI is also higher (>100 mL/g). Therefore, the sludge does not have good sedimentation characteristics, which is a consequence of the presence of dispersing biomass.

Figure 7. Oxygen consumption rate behavior



Source: Authors own creation.

The oxygen consumption rate was also monitored through the experimentation phases under the ϴc variation. Figure 7 shows the values for the OCR for the experimental test in each ϴc and the theoretical calculation.

4. CONCLUSIONS AND RECOMMENDATIONS

The aerobic process can be used as an alternative to treat wastewater from starch extraction. The biokinetics coefficients showed good values for starch removal, which are close to the coefficient values of domestic wastewater treatment. This similarity arises because starch is an organic substrate with high biodegradability. However, it is important to consider the effect of the organic load when the aerobic system is going to be applied as the only process to treat this kind of wastewater. This is due to the fact that the starch wastewater has a high COD concentration; therefore, a high HRT is needed to obtain good efficiency, as was the case in this study.

Consequently, it is suggested that future research should evaluate the maximum starch load which can be applied to the system without losing efficiency, and also, to evaluate whether there is a change in the biokinetics values when this load increases. However, the results obtained in this research are a good basis for the application of biological processes to treat wastewater from starch production.

5. ACKNOWLEDGMENTS

The authors would like to thank the GDCON group at the University of Antioquia, the Ministry of Science, Technology, and Innovation (Miniciencias), and the University of the Andes for funding this project.

6. REFERENCES

1. Wang RM, Wang Y, Ma GP, He YF, Zhao YQ. Efficiency of porous burnt-coke carrier on treatment of potato starch wastewater with an anaerobic-aerobic bioreactor. Chem Eng J. 2009;148(1):35–40.

2. Moghaddam AH, Sargolzaei J. A mini-review over diverse methods used in starchy wastewater treatment. Recent Patents Chem Eng. 2012;5(2):95–102.

3. Cai T, Lin H, Liu Z, Chen K, Lin Y, Xi Y, et al. IOP Conference Series: Earth and Environmental Science Starch wastewater treatment technology. IOP Conf Ser Earth Environ Sci. 2019;358:22054.

4. Antwi P, Li J, Boadi PO, Meng J, Shi E, Deng K, et al. Estimation of biogas and methane yields in an UASB treating potato starch processing wastewater with backpropagation artificial neural network. Bioresour Technol [Internet]. 2017;228:106–15. Available from: http://dx.doi.org/10.1016/j.biortech.2016.12.045

5. Sperling M Von, Chernicharo De Lemos CA. Biological Wastewater Treatment in Warm Climate Regions - Volume Two. 2005;634.

6. Inc M& E, Tchobanoglous G, David SH, Ryujiro T, Burton LF. Wastewater enginneering treatment and resource recovery. United Stated of America: McGraw Hill; 2014. 1966 p.

7. Molina JF, Rodriguez C, Bolívar EB. Manual de laboratorio procesos biologicos. 2008.

8. APHA. STANDARD METHODS. For the examination of water and wastewater. 23 nd. Rice EW, Baird RB, Eaton AD, Clesceri LS, editors. Washington: American Public Health Association, American Water Works Association, Water Environment Federation; 2017.

9. Khlifa Alfeluo J, Aljfairi KS, Hawege EF. p ': i3 ~ ' ¹ ' i i 'p i~¹~ ' ' (6 ') 2 (pi:pi 2021) : 91-100 Biokinetic Coefficients Determination for the Biological Treatment of Langat River. J Alasmarya Univ Basic Appl Sci. 2021;6(2):91–100.

10. Monod J. The growth of bacterial cultures. Ann Rev Microbiol. 1949;3:371–94.

11. Orozco Jaramillo A. Bioingenieria de aguas residuales. Teoria y diseño. Segunda. Acodal; 2014. 555 p.

12. Sponza DT, Uluköy A. Kinetic of carbonaceous substrate in an upflow anaerobic sludge sludge blanket (UASB) reactor treating 2,4 dichlorophenol (2,4 DCP). J Environ Manage. 2008

Jan;86(1):121–31.

13. Al-Malack MH. Determination of biokinetic coefficients of an immersed membrane bioreactor. J Memb Sci. 2006 Mar 1;271(1–2):47–58.

14. FranciscoJosé Molina Pérez. procesos biologicos. Medellín, Colombia: Reimpresos, Universidad de Antiquia; 2011. 105 p.

15. Mousavian S, Seyedsalehi · M, Paladino · O, Sharifi · P, Kyzas · G Z, Dionisi · D, et al. Determining biokinetic coefficients for the upflow anaerobic sludge blanket reactor treating sugarcane wastewater in hot climate conditions. Int J Environ Sci Technol [Internet]. 2019 [cited 2021 Sep 14];16(3):2231–8. Available from: https://doi.org/10.1007/s13762-017-1631-5

16. Romero Rojas JA. Tratamiento de aguas residuales. Teoria y principios de diseño. 1ra ed. Bogotá: Editorial Escuela Colombiana de Ingenieria; 2000. 1232 p.

17. Ain N, Awang NA. Civil and environmental engineering reports the relationship between the biokinetic parameters of an aerobic granular sludge system and the applied operating conditions. Civ Environ Eng reports. 2021;31:0161–71.

18. Molina Perez FJ. Procesos Biológicos. Pimera edi. Medellín, Colombia: Reimpresos, Universidad de Antiquia; 2011. 105 p.