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Evaluation of the operational status of an extended aeration activated sludge reactor through measurement of COD and nitrogen fractionation

Evaluación del estado de funcionamiento de un reactor de lodos activados de aireación extendida por medición del fraccionamiento de la DQO y el material nitrogenado

Jumara del Carmen Males Álvarez, Jorge Eduardo Guerrero Aguirre, Renato Gabriel Sánchez Proaño

Abstract

The rapid population growth in the southern part of Quito, driven by the pursuit of material prosperity, has increased wastewater production, leading to discharges into water bodies and affecting water quality. In this context, characterizing wastewater is crucial for reliable operational decision making. This research evaluates the WWTP Quitumbe bioreactor in terms of COD and nitrogen fractionation, considering the sludge age as a controlled variable. Wastewater samples were collected at inlet and outlet points of the bioreactor, and a physico-chemical method was used for COD fractionation. The results indicate a predominance of slowly biodegradable COD (X_S) and removal rates of 95% for biodegradable COD and 93% for ammonia nitrogen, demonstrating biodegradation capacity. Incomplete denitrification was confirmed, along with a cell retention time of 20 days. This study provides a solid foundation for enhancing the operational management of WWTP Quitumbe.

Keywords: Activated sludge age; Quitumbe WWTP; nitrification-denitrification.

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Resumen

El rápido crecimiento poblacional en el sur de Quito ha incrementado la producción de aguas residuales que generan descargas en cuerpos hídricos y afectan la calidad del agua. En este contexto, caracterizar las aguas residuales es crucial para la toma de decisiones operativas confiables. Esta investigación evalúa el biorreactor de PTAR Quitumbe en relación al fraccionamiento de DQO y nitrógeno, tomando en cuenta la edad del lodo como variable a controlar. Se muestrearon aguas residuales en puntos de entrada y salida del biorreactor, empleando métodos fisicoquímicos de fraccionamiento de DQO. Los resultados indican predominancia de DQO lentamente biodegradable (X_S) y eliminaciones del 95% en DQO biodegradable y 93% en nitrógeno amoniacal, demostrando la capacidad de biodegradación. Se confirmó la desnitrificación incompleta y un tiempo de retención celular de 20 días. Este estudio proporciona una base sólida para mejorar la gestión operativa de la PTAR Quitumbe.

Palabras clave: Edad del lodo activado; PTAR de Quitumbe; nitrificación-desnitrificación.

1. Introduction

The population growth of Quito has an annual rate of 1.17% (Durán et al., 2016), which is why there is an urgent need to investigate through technologies that effectively address the increasing problems of pollution arising from the rise in urban wastewater. From the perspective of the EPA (2000), the expansion of large cities along with industrialization and changes in consumption patterns have generated an ever-increasing demand for freshwater resources, leading to significant degradation of water bodies worldwide.

Currently, the city of Quito only has one wastewater treatment plant (WWTP) located in the Quitumbe sector. According to the consulting consortium LOTTI-ACS-BEGLAR, this plant can receive an average per capita wastewater load of 125.3 L/(inhabitants*day), which is equivalent to the amount of wastewater produced by approximately 55,047 people (LOTTI, 2017). To date, thorough investigations have not been conducted on the properties of biologically treated wastewater. Therefore, it is evident that the incoming water to the Quitumbe WWTP currently differs in composition from what was considered during the design phase.

Given this issue, there is a need to examine the fractionation of chemical oxygen demand (COD) and nitrogenous material in the wastewater subjected to biological treatment. A comprehensive analysis of COD and nitrogen content in these wastewater samples not only represents a crucial step in understanding the evolution and impact of changes in water characteristics over time but also plays a critical role in strengthening operational decisions of the plant. The availability of detailed and specific data regarding the fractionation of COD and nitrogen will provide, for the first time, a comprehensive view of the composition of wastewater undergoing treatment.

Carmona (2017) examined the evolution of COD fractionation at different stages of a WWTP using a physico-chemical approach. There was a significant decrease in easily biodegradable COD

(S_S) and, to a lesser extent, of slowly biodegradable COD (X_S). However, an increase in the fraction of non-biodegradable soluble COD (S_I) was recorded, attributed to the accumulation of microbial residues contributing to the content of inert material soluble in the effluent of the biological reactor. It was concluded that the biological treatment had a satisfactory performance, although work was needed to enhance its efficiency.

A study conducted by Henze (1992) evaluated wastewater characterization for modeling activated sludge processes in a completely mixed bioreactor. The relationship between the organic fraction of nitrogen and organic matter in the wastewater was revealed. Similarly, it was found that S_I and S_S constitute approximately 25% and 20% of the ${}_{T}$COD, respectively. Finally, it was concluded that there are various techniques for organic fractions, but lack of experience affects result interpretation.

The proposed research aims to examine the performance of a bioreactor by analyzing the fractionation of COD and nitrogenous material through laboratory tests and in-situ monitoring. The sampling frequency in the bioreactor was defined based on an operational parameter. Additionally, the relationship between nitrogen species and factors such as pH, dissolved oxygen, and conductivity was investigated to establish optimal operative ranges. Finally, the sludge age was determined by measuring the variability of COD and nitrogen compounds, according to their fractions.

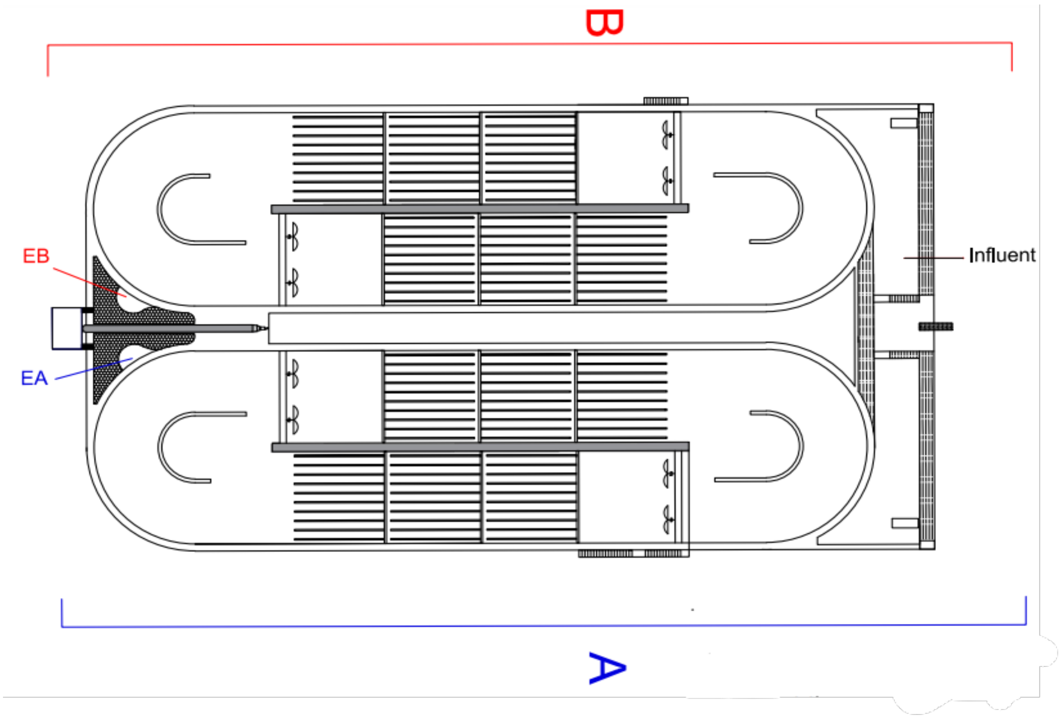
2. Method

The methodology, in terms of wastewater characterization, was applied to the inflow and outflows of the bioreactor at the Quitumbe Wastewater Treatment Plant WWTP. This plant is designed to treat urban-domestic wastewater, which is generated at the household level by the population residing in the service area. It is complemented by low-impact commercial and industrial activities that, while capable of contributing moderate organic loads, should not include substances inhibitory to bacterial metabolism. (LOTTI, 2017). A physico-chemical method was used to fractionate the COD, and stoichiometric equations were used for the nitrogen.

Field Sampling

Samples were collected from operational units A and B of the bioreactor at the Quitumbe WWTP as established by the NTE INEN 2169 (2013) standard, which outlines sampling, handling, and preservation of samples. Next, three sampling points were selected: the influent selector, the effluent from unit A, and the effluent from unit B. A total of five replicates were taken on Fridays in the month of March 2023, during the noon hours. Lastly, AUTOCAD software was used for the design of the bioreactor, allowing a better spatial understanding during field sampling (see Figure 1).

Figure 1. Schematic Representation of the Biological Treatment



Note. The biological treatment at the Quitumbe WWTP comprises two parallel units, A and B. The influent wastewater and the recirculated sludge converge at the influent selector. The effluent chambers receive the effluents from the main chambers of both units and direct them towards the sedimentation tanks.

On the other hand, the sludge collection was carried out at a depth of two meters. This choice was based on considering the turbulence present in the influent and effluent zones. Likewise, it was considered that the bioreactor is of complete mixing and exhibited constant movement throughout the study. At each sampling point, measurements of pH, dissolved oxygen (DO), and conductivity were conducted using a multiparameter instrument by HACH, model HQ40d. This instrument consists of two probes that enable simultaneous measurements of parameters such as pH, conductivity, DO, among others (Liu et al., 2018).

Finally, due to the WWTP has an internal laboratory, the research and chemical analyses were conducted on a single site. This minimized the transportation of samples, thus restricting it from the bioreactor to the plant's facilities. This ensured compliance with the guidelines of the NTE INEN 2176 (2013) standard, which pertains to sampling techniques. For the preservation and storage time of parameters analysis such as: COD, biochemical oxygen demand (BOD), total nitrogen, nitrates, ammonium, and total suspended solids (TSS), the guidelines established by the NTE INEN 2169 (2013) standard were followed.

Laboratory Processing

The laboratory processing allowed the execution of physico-chemical analyses following the procedures established in the Standard Methods for the Examination of Water and Wastewater (WPCF, 1992). This procedure was carried out after each sampling event. The process involved examining parameters related to total nitrogen concentration, nitrates, ammonia nitrogen, as well as analyzing COD fractions. Regarding the determination of $_{T}$COD and $_{S}$COD, a 0.2 mL sample was extracted using a micropipette. The key distinction lay in the quantification of $_{S}$COD, where a vacuum pump was employed in combination with a fiberglass filter. This sample volume was deposited into COD vials, which were subsequently introduced into a digester. According to Leon-Huallpa et al., (2023), this device effectively triggers the digestion of organic matter contained in the sample. Following this stage, the measurement of the resulting concentrations was carried out using a spectrophotometer. As noted by García (2018), this instrument assesses the intensity of light absorbed by the sample, adapting to different wavelengths.

The measurements of Total 5-Day Biochemical Oxygen Demand ($_{T}BOD_5$) and Soluble 5-Day Biochemical Oxygen Demand ($_{S}BOD_5$) were conducted using the OxiTop® measurement device, in which the samples were placed for respirometry analysis. In the case of the $_{S}BOD_5$, a vacuum pump along with a fiberglass filter was used to efficiently separate the biomass. Regarding the reagents, nitrification inhibitors and sodium hydroxide were added to adjust the test conditions. Subsequently, the samples were placed in an incubator for their development (Almutairi, 2020).

Regarding the analysis of nitrates, ammonia, and total nitrogen, 5 mL of sample was used for each analysis. After this, the samples underwent a filtration process. Subsequently, for nitrate determination, the NitraVer®5 reagent by HACH was employed; for ammonia, 1 mL of Nessler reagent along with 3 drops of mineral stabilizer and Kenjdhal's total nitrogen indicator solution (TKN) were used. For total nitrogen, total nitrogen vials and a digester were used. Finally, the concentrations of these parameters were measured using a spectrophotometer.

Table 1. Suggested formulas for calculating COD (Chemical Oxygen Demand) fractions.

COD Fraction	Formula
Easily biodegradable COD	$_{Soluble}BOD5$
Slowly biodegradable COD	$_{Total}BOD5_{-Soluble}BOD5$
Non- biodegradable soluble COD	$_{Soluble}COD\text{-}\ _{Soluble}BOD5$
Non- biodegradable particulate COD	$(_{Total}COD\text{-}_{Total}BOD5)\text{-}(_{Soluble}COD\text{-}_{soluble}BOD5)$

Note: The table presents the formulas and equivalences to be used for the subsequent calculation of COD fractions.

Table 2. Suggested equations for calculating nitrogenous material fractions.

Nitrogenous material fraction.	Formula
Nitrate nitrogen	$X\frac{mgNO_3}{L} \times \frac{14mg\ N}{62\ mgNO_3}$
Ammonia nitrogen	$X\frac{mgNH_3}{L} \times \frac{14mg\ N}{17\ mgNH_3}$
Total nitrogen	A. nitrogen + N. nitrogen + O. nitrogen
Organic nitrogen	T. nitrogen – A. nitrogen – N. nitrogen

Note: The formulas and stoichiometric calculations used for the subsequent calculation of nitrogen-containing material fractions are presented.

The sludge age or SRT (Solid Retention Time), according to Espinoza (2017), represents the average time that sludge remains in the biological reactor and is defined as the ratio between the total amount of sludge present in the aeration tank and the amount of excess sludge purged daily. Equation 1 incorporates various key parameters. The volume of the bioreactor (V), expressed in cubic meters (m^3), the total suspended solids present in the operational units (TSS_{Reac}), measured in milligrams per liter (mg/L), and the total suspended solids in the clarifier (TSS_{Sed}), also in mg/L, were used. Additionally, the daily sludge purging flow rate (Q_p), represented in cubic meters per day (m^3/d), was included.

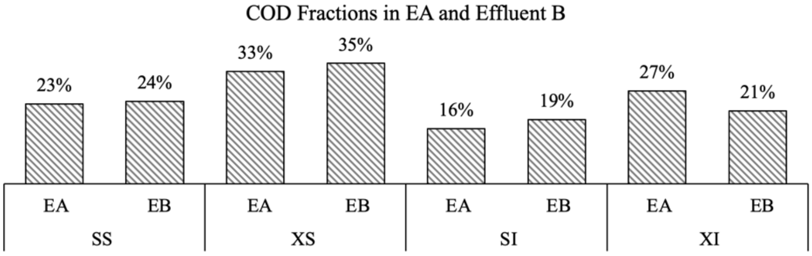
$$\theta_c = \frac{V * TSS_{Reac}}{Q_P * TSS_{Sed}}$$

3. Results

COD Fractionation Results

The results revealed a common and significant characteristic of the experimental observations. The slowly biodegradable COD should be considered as the main limiting component of the heterotrophic growth rate in biological treatment systems. While it is true that a significant reduction in the S_S fraction was indeed identified, this proportion would be expected to be much lower; this is due to increases in flow rates and modifications in organic matter since the plant's commissioning.

Figure 2. Percentage of COD Fractions in the Bioreactor Effluents



Note. The bars represent the percentages of COD fractions present in the bioreactor effluents.

The fraction that recorded the highest value corresponded to the slowly degradable COD. This pattern is attributed to changes in the properties of the incoming wastewater to the plant. At this point, Haider et al., (2003) determined and agreed that the effluent quality with respect to non-biodegradable compounds improves at higher sludge ages, due to the accumulation of residual metabolic products. This would justify why a high percentage was recorded in this research, as a sludge age of 21 days was determined.

In response to Figure 2, Myszograj et al., (2017) emphasize that each COD fraction has a specific origin. The S_S fraction comes from industrial wastewater originating from fruit and vegetable processing. Inert COD components can arise in the influent or be generated as microbial byproducts related to growth and decomposition. Additionally, polymerized organic compounds are a source of contamination directly associated with the X_S fraction. In this regard, Troya, (2023) identifies those direct discharges from illegal slaughterhouses occur in the Ortega, Sanshayacu, and El Carmen creeks, which enter the Quitumbe WWTP system. According to Sayed et al., (1988), bacteria breaking down these substrates might not meet their metabolic needs, resulting in an increase in the X_S fraction.

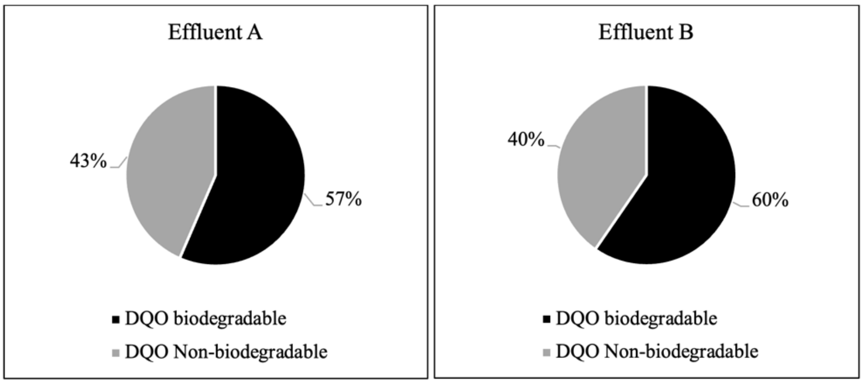
The high percentage of the slowly biodegradable COD fraction in the Quitumbe wastewater treatment plant (WWTP) results in a relative efficiency lower than that established for an oxidation ditch-type bioreactor. Therefore, adjustments in operational conditions are recommended, as explained by Agbewornu et al., (2021). In cases where slowly biodegradable COD fractions are high, it’s advisable to increase biomass concentration, enhance retention capacity, and optimize aeration. These measures are crucial for improving the COD degradation capacity in the bioreactor and achieving greater process efficiency.

Regarding COD fractionation, there isn’t a specific method for conducting measurements, which leads to each researcher adapting it to their needs. In this context, the results obtained in Figure 2 are reinforced by relating them to the findings of Henze (1992). The author undertook the analysis of domestic wastewater using a physico-chemical approach within the context of an oxidation ditch, and a similar composition was identified. On the other hand, when contrasting with the COD fraction percentages obtained through chemical-biological methods like that used by Sadecka et al., (2011), values of S_S ranged between 24% and 32%, S_I between 8% and 11%, X_S

between 43% and 49%, and X_I between 11% and 20%. Their results indicated consistent variations, which could be attributed to the researcher's method adaptation.

Figure 3 displays the percentages of biodegradable and non-biodegradable COD present in the effluents. The results indicated that the biodegradable COD fraction constitutes 57%, while the non-biodegradable COD fraction represents 43% in the effluent corresponding to operational unit A. When comparing the findings, the analysis of operational unit B reveals a proportion of 60% biodegradable COD, as opposed to a non-biodegradable COD fraction corresponding to 40%. The results underscored the effectiveness of the biological treatment, as they remain within the ranges considered efficient.

Figure 3. Existing percentage of biodegradable and non-biodegradable COD in the effluent from operational units A and B.



Note: The figures displayed the percentages of biodegradable and non-biodegradable COD found in the effluent from operational units A and B during the study period.

The findings from Figure 3 align with the results obtained in investigations conducted by Carmona (2017) and Orhon et al. (1997), where approximate percentages of biodegradable COD at 58% and non-biodegradable COD at 42% were observed. This confirmed the responsiveness of the wastewater at the Quitumbe WWTP to undergo biodegradation processes. In contrast, the biodegradable COD exhibits a slight overestimation compared to the findings reported by Wu et al. (2014). This discrepancy could be attributed to differences in measurement methods used and the specific conditions under which the treatment plant in their study operates.

Removal percentages of COD and nitrogenous material

The removal percentages of $_{Total}$COD were 80.46% and 82.59% in the effluent from units A and B, respectively. Additionally, a removal index of easily biodegradable COD of 95% was achieved in both units. These results are significant and demonstrate the effectiveness of the treatment system implemented in the analysis units. The removal of Total COD in the effluent indicated a substantial reduction in the organic load present in the wastewater, which is crucial for environmental protection and ensuring the quality of the treated water.

Table 3. Removal of COD and Ammoniacal Nitrogen in the effluent of the biological treatment units

		% Removal		
Points	$_{Total}$COD	$_{rb}$COD	A. Nitrogen	T. Nitrogen
EA	80,46	95,42	91,74	13,76
EB	82,59	95,77	94,80	14,02

Note: The table displays the elimination percentages obtained for Total COD, Easily Biodegradable COD, Ammoniacal Nitrogen, and Total Nitrogen from samples taken in the effluent of units A and B in the biological treatment system.

The parallel treatment lines of the bioreactor exhibit comparable and efficient removals. Table 3 demonstrated that the percentages of ammoniacal nitrogen removal exceeded 91%. This finding aligns with the study by Luo et al. (2020), which reported a similar removal efficiency of 91% in an oxidation ditch type bioreactor. According to Shammas & Wang (2009), oxidation ditches in general achieve removals greater than 90% for BOD, suspended solids, and ammoniacal nitrogen, demonstrating a typical behavior for the bioreactor at the Quitumbe WWTP.

Furthermore, it was observed that the behavior of the bioreactor in relation to Total COD removal percentages is relatively low, with values not exceeding 83%. In studies conducted by Al-Wardy et al. (2021), it was found that if the characteristics of the mixed liquor have undergone substantial changes in their properties since the plant's commissioning, carousel-type or oxidation ditch bioreactors reduce their efficiency to 85%. This would indicate that the water characterized for plant design purposes shows changes in its composition. Finally, when analyzing the percentage of total nitrogen removal, it is highlighted that the microorganisms are not adapted to perform denitrification processes. According to Koropczuk (2019), nitrogen total removal percentages of 90% are achieved in oxidation ditches with aged sludge. This statement supports the results obtained in this study.

Nitrogen fractionation

The total nitrogen values were as follows: in sampling 1, the effluents recorded a minimum value of 90 mg/L. On the other hand, the maximum concentration in the influent was recorded in sampling 5 with 201 mg/L. Regarding organic nitrogen, in sampling 1, the effluents registered overall minimum values of 88.1 mg/L for A and 88.2 mg/L for B, while in the influent, the maximum value was 187.6 mg/L, corresponding to sampling 4. Concerning nitrate nitrogen content, the effluent from unit B (EB) had 1.8 mg/L in sampling 4; the minimum value was 0.5 mg/L, which was found in the influent. In relation to ammonia nitrogen, the maximum result was 16.1 mg/L observed in sampling 2 of the influent.

Table 4. Results of nitrogen fractionation found in the samples from the units

	Nitrogen Fractionation											
Sampling	Total Nitrogen (mg/L)			$S_{Organic}$ (mg/L)			S_{NO3} (mg/L)			$S_{N\text{-}NH3}$ (mg/L)		
	IF	EA	EB	IF	EA	EB	IF	EA	EB	IF	EA	EB
M1	98,0	90,0	90,0	82,3	88,1	88,2	0,5	0,9	0,8	15,2	1,0	1,0
M2	101,0	95,0	92,0	84,0	91,4	89,6	0,9	1,7	1,6	16,1	1,9	0,8
M3	164,0	114,0	126,0	150,2	111,0	123,6	1,3	1,6	1,6	12,6	1,4	0,8
M4	199,0	179,0	173,0	187,6	176,4	171,0	1,3	1,6	1,8	10,1	1,0	0,2
M5	201,0	180,0	175,0	186,2	178,2	172,0	1,5	1,6	2,4	13,4	0,2	0,6
	152,6	131,6	131,2	138,1	129,0	128,9	1,1	1,5	1,6	13,5	1,1	0,7

Note. The table presents the concentrations of nitrogen fractions in the samples collected at the influent (inlet) and effluent (outlet) of units A and B.

Organic nitrogen registered similar average values in the effluents, presumably due to its recalcitrant nature, which led the influent organic nitrogen to become a substantial fraction of nitrogen in the final effluent (Westgate & Park, 2010). According to Romero (2004), for the microorganisms present in the bioreactors to efficiently degrade organic nitrogen, sufficient contact time between the microorganisms and the contaminant is required. In this case, the mean cell retention time is essential to determine whether there is nitrogenous material consumption by the microorganisms.

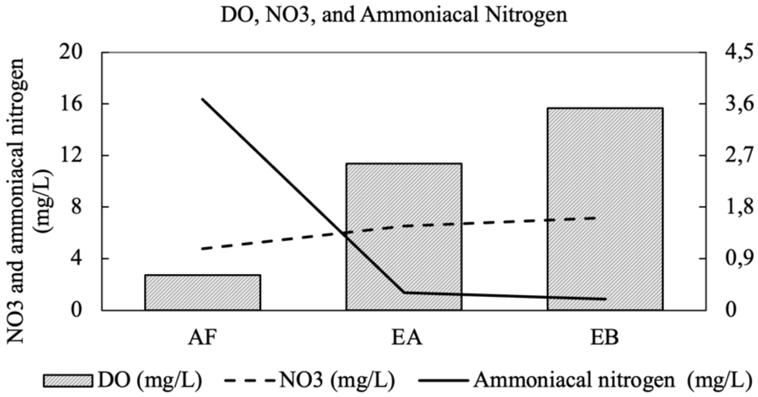
According to Yu (2012), nitrifying bacteria are aerobic autotrophic organisms characterized by a low reproduction rate and an extended generation cycle. To enhance biological denitrification capacity and improve nitrogen removal efficiency, it is essential to have a cell retention time exceeding 25 days. When the cell retention time is insufficient, a portion of nitrifying bacteria proliferation remains incomplete and is carried away by the water, triggering an incomplete denitrification reaction. These factors explain why the total nitrogen and organic nitrogen results in this research showed significantly low variation in the effluents.

It’s worth clarifying that Henze et al. (1995) mention that the primary function of bioreactors lies in carbonaceous matter removal. If additional nitrogen removal is sought, the incorporation of supplementary units dedicated to nitrification is advised. Nevertheless, an analysis conducted at the Quitumbe WWTP revealed notable percentages of ammoniacal nitrogen removal, even though an equivalent level of removal in terms of total nitrogen was not achieved. This outcome indicates that the denitrification process did not proceed completely.

Relationship among nitrogen species based on pH, conductivity, and DO

The bioreactor effluents demonstrated dissolved oxygen values exceeding 2 mg/L. According to LOTTI (2017), during the biological phase, it is essential to ensure a dissolved oxygen level within the range of 1 to 5 mg/L, with an optimal value between 2 and 3 mg/L. This is crucial to provide the optimal amount of oxidant required for the biochemical reactions involved in the degradation process of the organic pollutants. Therefore, the behavior of the Quitumbe WWTP bioreactor has shown proper system oxygenation and favorable conditions for microbial activity.

Figure 4. Behavior of nitrogen species and dissolved oxygen

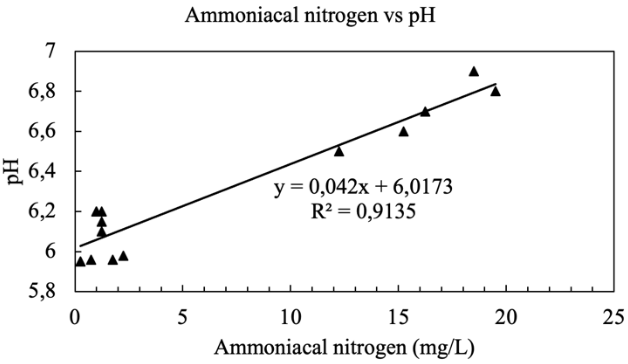


Note. The diagram schematically represents the evolution of dissolved oxygen and nitrogen species during the samplings.

On the other hand, a clear increase in nitrate concentration was found in effluents A and B with values of 6.52 mg/L and 7.16 mg/L respectively. According to Mandt & Bell (1982), the presence of nitrates in the effluent of a carousel-type biological reactor indicates that microorganisms have efficiently carried out the conversion of ammonia to nitrite and subsequently to nitrate through the nitrification process. However, it is relevant to highlight that in the biological system of the Quitumbe WWTP, a complete denitrification process is not observed.

Figure 5 found a coefficient of determination of 0.9135 between ammoniacal nitrogen and pH, indicating that changes in pH can have a considerable impact on ammoniacal nitrogen levels. In this context, Romero (2004) stated that if the environment in the bioreactor is acidic, ammoniacal nitrogen converts to ammonium, while basic environments allow the formation of ammonia. Given the proposition, the relationship between ammoniacal nitrogen and pH in the results of this study is supported.

Figure 5. Contrast between Ammoniacal Nitrogen and pH



Note. The figure depicts the correlation between ammoniacal nitrogen and pH.

The results align with Ruiz et al., (2003), who found that in the acidic pH range of 7.85 to 6.45, nitrification in aerobic systems remains unaffected. However, a pH below 6.35 completely inhibits nitrification and the efficiency of the carousel bioreactor. This finding is supported by Yu, (2012), who discovered that a pH lower than 6 affects the growth of nitrifying bacteria since they prefer a pH close to 8 for their optimal growth in nitrification.

Sludge Age

Regarding the F/M ratio, a value of 0.18 kgCOD/kgMLVSS*d was obtained (see Table 5), which aligns with the observations of Romero (2004), who mentions that in oxidation ditches, this ratio ranges from 0.05 to 0.3, hence, there is a 90% removal of BOD, which supports the findings regarding the removal of easily biodegradable COD in this research. On the other hand, the volatile suspended solids of the mixed liquor registered a concentration of 3100 mg/L, which is relatively low for a biological treatment. Therefore, it is necessary to increase this concentration to enhance the overall efficiency.

Table 5. Parameters obtained in the activated sludge system

Parameters	Acronims	Value	Units
Hydraulic Retention Time (HRT)	θ	0,83	d
BOD_5	So	455	mg/L
Mixed Liquor Suspended Solids	MLSS	3700	mg/L
Aeration Tank Volume	V	12160	m^3
Sludge Purge Flow Rate	Qr	350	m^3/d
Total S. S. in Settler	TSS sed	6550	mg/L
Volatile S. S. in Mixed Liquor	VSS ML	3100	mg/L
Cell Retention Time	θc	20	d
Food to Microorganism Ratio	F/M	0,18	$kg_{BOD5}/kg_{VSSML}*d$

Note. The calculation of sludge age and F/M ratio was performed using parameters established in the WWTP along with others obtained through laboratory analysis.

Most authors agree on a sludge age of 20 to 30 days; however, this research identified a sludge age of 20 days, which contrasts with the observation of Ghangrekar (2022) who emphasizes the need for an extended cellular residence time to maintain the endogenous growth phase of microorganisms. In conclusion, continuous monitoring of this parameter is important since, if its value reaches excessively high levels, it could result in flocs composed mainly of mineralized residue derived from endogenous respiration, limiting their flocculation capacity. On the other hand, if the value is too low, there is a tendency for bacterial dispersion in the growing flocculant environment.

The sludge age determined in this study has a significant impact on the capacity of microorganisms to consume total and organic nitrogen, as shown in Table 5. According to Yu (2012), this effect is attributed to the longer growth cycle of nitrobacter bacteria compared to nitrosomonas. Nitrobacter have a slower growth cycle and a shorter cellular retention time, making them more susceptible to being washed away with water. As a result, interruption and even inhibition of the denitrification process occur.

Consequently, a young sludge does not favor the nitrification reaction, and it is essential to find a balance in the cellular retention time. In this way, Rong-sen (2006) asserts that maximizing nitrification efficiency is achieved, ensuring proper removal of both organic nitrogen and ammoniacal nitrogen in their two stable solubility forms. Achieving proper synchronization of cellular retention times is crucial to enhancing the process and ensuring that nitrifying organisms effectively fulfill their function.

4. Conclusions

The findings suggest that the easily biodegradable COD is a relatively small fraction of the total COD content in wastewater. As a result, the biological treatment systems at the Quitumbe Wastewater Treatment Plant are not primarily governed by the depletion of easily biodegradable organic compounds, but rather by the hydrolysis of slowly biodegradable organic compounds, a process much slower in comparison to heterotrophic growth.

In the effluent of operational unit, A (EA), the average removal rate of biodegradable COD was 95.42%, and in the effluent of operational unit B (EB), it was 95.77%, demonstrating effectiveness in removing organic load. Additionally, the removal of ammonia nitrogen was 91.74% (EA) and 94.80% (EB), indicating nitrification. Despite this, the denitrification process was not fully completed, as the cell retention time was found to be lower than required for carousel-type bioreactors. Nevertheless, the results validate the acceptable performance of the process, significantly reducing the pollutant load and improving the quality of the treated water.

In the context of COD fractionation, a notable limitation lies in the absence of a specific method for conducting measurements. Although traditional physicochemical methods are employed to analyze water composition, it is crucial to complement them with biological approaches to accurately determine COD fractions, thus avoiding an overestimation of biodegradable fractions.

Further studies are needed to delve into exploring the correlation between various in-situ parameters, including those not addressed in this study. Additionally, the assessment of fractionation for other nutrients, such as phosphorus, is suggested to obtain a more comprehensive and complete understanding of the processes.

References

Agbewornu, K., Adyel, T., & Zhai, J. (2021). Optimizing nitrogen removal in a hybrid oxidation ditch. *Journal of Environmental Chemical Engineering*, *9*(4), 105443.

Almutairi, M. (2020). Method development for evaluating the effectiveness of hydrocarbons on BOD, UBOD and COD removal in oily wastewater. *Water Science and Technology*, *81*(12), 2650-2663.

Al-Wardy, H., Al-Saadi, M., & Alquzweeni, S. (2021). Performance Evaluation of Al-Muamirah Wastewater Treatment Plant. *IOP Conference Series: Earth and Environmental Science*, *877*(1), 012027.

Carmona, J. (2017). *Análisis de las fracciones de DQO en las aguas de la planta de tratamiento de aguas residuales (PTAR).*

Durán, G., Costa, M., & Mérida, J. (2016). Crecimiento, segregación y mecanismos de desplazamiento en el periurbano de Quito. *Íconos: Revista de Ciencias Sociales*, *56*, 123-146.

EPA, U. (2000). *Wastewater Technology Fact Sheet: Oxidation Ditches*. United States Environmental Protection Agency

Troya, F. (2023). *Los programas de recuperación y restauración de quebradas en áreas urbanizadas del Distrito Metropolitano de Quito* [Master's Thesis, Flacso Ecuador].

Ghangrekar, M. (2022). *Wastewater to Water: Principles, Technologies and Engineering Design*. Springer Nature.

Haider, S., Svardal, K., Vanrolleghem, A., & Kroiss, H. (2003). The effect of low sludge age on wastewater fractionation (SS, SI). *Water Science and Technology*, *47*(11), 203-209.

Henze, M. (1992). Characterization of wastewater for modelling of activated sludge processes. *Water Science and Technology*, *25*(6), 1-15.

Henze, M., Gujer, W., Mino, T., Matsuo, T., Wentzel, M. C., & Marais, R. (1995). Wastewater and biomass characterization for the activated sludge model no. 2: Biological phosphorus removal. *Water Science and Technology*, *31*(2), 13-23.

Huallpa, F., Alfaro, R., Ramos, E., Zapana, M., Mamani, W., & Quispe, G. (2023). Efficiency of prefabricated biodigesters in the treatment of domestic wastewater in dispersed rural localities. *E3S Web of Conferences*, *405*, 04035.

Liu, C., Wang, Q., Xu, D., Wang, S., & Du, Y. (2018). Study on nitrification characteristics of livestock wastewater treated with SBR. *IOP Conference Series: Earth and Environmental Science*, *170*(3), 032071.

LOTTI. (2017). *Manual de Operación y Mantenimiento de la PTAR Quitumbe: Vol. XI.*

Luo, Y., Yao, J., Wang, X., Zheng, M., Guo, D., & Chen, Y. (2020). Efficient municipal wastewater treatment by oxidation ditch process at low temperature: Bacterial community structure in activated sludge. *Science of The Total Environment*, *703*, 135031.

Mandt, G., & Bell, A. (1982). Oxidation ditches in wastewater treatment. *Ann Arbor Science, Ann Arbor MI. 1982. 169.*

Morales Fiallos, F., Sánchez Proaño, R., & Acosta Lozada, R. (2019). Tratamiento de efluentes de lubricadoras y lavadoras de autos mediante un sistema de lodos activados de lechos suspendido a escala de laboratorio. *Ciencia Digital, 3*(1), 170-179.

Myszograj, S., Koropczuk, E., & Jakubaszek, A. (2017). COD fractions-methods of measurement and use in wastewater treatment technology. *Civil and Environmental Engineering Reports*, *24*(1), 195-206.

NTE INEN 2169. (2013). *Agua. calidad del agua. muestreo. manejo y conservación de muestras.*

NTE INEN 2176. (2013). *Agua. Calidad del agua. Muestreo. Manejo y conservación de muestras*

Orhon, D., Ateş, E., Sözen, S., & Çokgör, U. (1997). Characterization and COD fractionation of domestic wastewaters. *Environmental Pollution*, *95*(2), 191-204.

Koropczuk, E., & Myszograj, S. (2019). New approach in COD fractionation methods. *Water*, *11*(7), 1484.

Romero, A. (2004). *Tratamiento de aguas residuales, teoría y principios de diseño*. CO, Escuela Colombiana de Ingenieros.

Rong-sen, D. (2006). *Oxidation ditch wastewater treatment theory and technology [M]*. Chemical Industry Press.

Ruiz, G., Jeison, D., & Chamy, R. (2003). Nitrification with high nitrite accumulation for the treatment of wastewater with high ammonia concentration. *Water research*, *37*(6), 1371-1377.

Sadecka, Z., Myszograj, S., & Kisielewicz, M. (2011). Aspekty prawne przyrodniczego wykorzystania osadów ściekowych. *Zeszyty Naukowe. Inżynieria Środowiska/Uniwersytet Zielonogórski*, *144*(24), 5-17.

Sánchez Proaño, R., & García Gualoto, K.J. (2018). Tratamiento de aguas residuales de cargas industriales con oxidación avanzada en sistemas convencionales. *La granja. Revista de Ciencias de la Vida, 27*(1), 103-111.

Sayed, S., van der Zanden, J., Wijffels, R., & Lettinga, G. (1988). Anaerobic degradation of the various fractions of slaughterhouse wastewater. *Biological Wastes*, *23*(2), 117-142. https://doi.org/10.1016/0269-7483(88)90069-9

Shammas, K., & Wang, K. (2009). Oxidation ditch. *Biological treatment processes*, 513-538.

Westgate, J., & Park, C. (2010). Evaluation of proteins and organic nitrogen in wastewater treatment effluents. *Environmental science & technology*, *44*(14), 5352-5357.

WPCF, A.A. (1992). Métodos normalizados para el análisis de aguas potables y residuales. *Versión en español. Ediciones Díaz Santos.*

Wu, J., Yan, G., Zhou, G., & Xu, T. (2014). Wastewater COD biodegradability fractionated by simple physical–chemical analysis. *Chemical Engineering Journal*, *258*, 450-459.

Yu, L. (2012). Effect of SRT on nitrogen and phosphorus removal in modified carrousel oxidation ditch process. *Advanced Materials Research*, *396*, 1995-2001.

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Conflict of interest

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