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Design and Validation of a Nitrification and Denitrification Scheme for Wastewater Treatment. A Case Study in the Dominican Republic

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Abstract
Wastewater treatment requires systems that provide the guarantee that the treated water has adequate characteristics to avoid pollution. The objective of this research is to design and validate a scheme that contemplates nitrification and denitrification for wastewater treatment in the Dominican Republic. The designed scheme was implemented as follows: a 90-minute cycle, corresponding to 60 minutes in the nitrification process and 30 minutes in denitrification. During this cycle, the concentration of oxygen, ammonium and nitrate was allowed to fluctuate and the concentration of suspended solids was limited in the range of 8,500 to 18,000 mg/l (Table no 1). The scheme described was monitored and controlled in a continuous, automated manner, via the SCADA system. The scheme was subjected to experimentation for three months, with analyses carried out every week. The results have shown that the scheme designed is adequate to provide water with the quality characteristics required by Dominican standards for water leaving the treatment plants (effluent). In this sense, all the parameters analyzed in the influential of the PTAR Rafey have improved the quality of its polluting load at the outlet of the treated water (effluent), always being located below the permissible values in the Dominican standards. In future research, it should be analyzed whether the wastewater treatment scheme proposed by this research improves the nutritional characteristics of the sewage sludge that is generated in the process.
Key Word: nitrification, denitrification, wastewater, treatment, water.

I. Introduction

The National Sanitation Strategy of the Dominican Republic[1] indicates that 90% of the wastewater collected by the networks of 37 sanitary sewerage systems in the country does not receive any type of treatment, a situation that represents a serious environmental problem and a threat to the health of the population. In Santiago de los Caballeros, the second largest city in the Dominican Republic in socio-economic terms, 76% of the wastewater generated is discharged into waterways without any treatment process.

In the province of Santiago, the domestic wastewater treatment systems have eight treatment plants in service, with an installed capacity of 137,116.80 cubic meters per day, operated by the Santiago Aqueduct and Sewer Corporation (CORAASAN). One of the missions of this institution is to manage wastewater treatment systems, complying with the quality standards in force in the country and thus consolidate the continuous improvement of processes and environmental conservation.

Wastewater treatment requires systems that provide the guarantee that the treated water has adequate characteristics to avoid pollution. In this sense, there are different types of systems and schemes for wastewater treatment, although each of them also has an impact on the quality of the sludge generated, which can be used, when it meets the appropriate characteristics, as a soil recovery system and as a friendly fertilizer for mass use[2-5].

The objective of this research is to design and validate a scheme that contemplates nitrification and denitrification for wastewater treatment in the Dominican Republic. The purpose of the nitrification and denitrification process is to eliminate the nitrogen in the waste, i.e. it is a microbiological process in which ammonium is oxidized by autotrophic bacteria to nitrate in the presence of oxygen and inorganic carbon (nitrification) and then this nitrate is reduced by heterotrophic bacteria to molecular nitrogen gas in the absence of oxygen and in the presence of organic carbon (denitrification).

The wastewater treatment scheme proposed in this research aims to improve and reduce the pollutant characteristics of the treated water and, subsequently, in future research, to further investigate the nutritional characteristics of the wastewater sludge generated in the process.

II. Methodology

Experimental area

The experimental area of this research is the Rafey Wastewater Treatment Plant (WWTP), located in Santiago de los Caballeros. This plant was built in 1976, with a capacity of 890 liters per second (lps). In 2005, a rehabilitation process began with the improvement of equipment and physical infrastructure, increasing operating capacity to 1,217 lps. During the improvements, a modification of process types was also made, such as the replacement of the conventional activated sludge system to an activated sludge system with extended aeration, including the incorporation of band filters for sludge dewatering.

Currently, the entire treatment system is automated and has a SCADA (Supervisory Control And Data Acquisition) system for the control and management of recorded information. The plant was put into operation with this new system on May 12, 2006, with a pollutant removal efficiency of 90%, meeting the national quality standards established by the Ministry of the Environment and Natural Resources of the Dominican Republic.

Experimental design

The designed scheme was implemented as follows: a 90-minute cycle, corresponding to 60 minutes in the nitrification process and 30 minutes in denitrification. During this cycle, the concentration of oxygen, ammonium and nitrate was allowed to fluctuate and the concentration of suspended solids was limited in the range of 8,500 to 18,000 mg/l (Table no 1). The described scheme was monitored and controlled in a continuous, automated manner via the SCADA system installed in the treatment plant, which facilitated immediate and constant decisions regarding the control of the limits established for the defined parameters. The activated sludge system operated with a minimum sludge age of 15 days, which allowed for the completion of nitrification and excellent effluent quality. The scheme was subjected to experimentation for three months, with analyses carried out every week.

Table no 1: Parameters to check.

Parameter	Ranking	Units
Oxygen	0-5.0	Mg/l
Ammonium	0.4-3.0	Mg/l
Nitrate	0.4-3.0	Mg/l
Suspended solids	8,500 – 15,000	Mg/l

Source: own elaboration.

During the experimental period of the scheme, twelve analyses of the water received at the plant before treatment (influent) and the same number of analyses of the water discharged after treatment (effluent) were carried out. Table no 2 shows the parameters measured and the analytical method used for each sample. The samples were obtained in the PTAR Rafey by the Water Laboratory of CORAASAN, which is certified by the Ministry of Environment and Natural Resources of the Dominican Republic.

Table no 2: Parameters and analytical methods.

Parameter	**Symbol**	**Unit**	**Analytical method**
Chemical Oxygen Demand	COD	Mg/l	SM-5220-B
Suspended Solids	SS	Mg/l	SM-2540-D
Total Nitrogen	N	Mg/l	SM-4500-N-C
Ammonium Nitrogen	N-NH4	Mg/l	SM-4500-NH3
Biochemical Oxygen Demand	BOD_5	Mg/l	SM-5210-B
Total Phosphorus	P	Mg/l	SM-4500-P-C
Orthophosphates	P-PO4	Mg/l	SM-4500-P
Potential of Hydrogen (pH)	pH	-	SM-4500-H+.B
Dissolved Oxygen	DO	Mg/l	SM-4500-O-G

Source: own elaboration.

Also, a microscopic observation of the biological processes was carried out in a tank to determine the protozoa and metazoa. To carry out this observation, the steps established by Bajarano and Escobar[6] were followed.

Data analysis

The data report was prepared by LAMENER. Subsequently, the data was tabulated in Microsoft Excel format and analysed with the IBM SPSS 24 statistical software.

III. Results and Discussion

To verify the performance of the nitrification and denitrification cycle scheme for Biosolids production, specifically its impact on wastewater treatment, we analyze below the behavior of the parameters linked to the processes carried out in the activated sludge biological process tank with extended aeration.

COD is one of the most widely used parameters in the characterization of organic pollutants, and they are used to determine the approximate amount of oxygen that will be required to biologically stabilize the organic matter present. The scheme designed presents an average COD removal efficiency of 91%, and a maximum of 96%, during the time interval analyzed. With reference to the maximum allowable COD value of municipal wastewater discharges into surface waters, the system complies with the value established in the Dominican Environmental Standard on Discharge Control to Surface Waters, Sanitary Sewerage and Coastal Waters, as shown in Table no 3.

Table no 3: COD influential and effluent values.

COD				
Week	**Influential COD (mg/l)**	**Effluent COD (mg/l)**	**Permissible limits (mg/l)**	**Efficiency**
1	115	10	130	91%
2	182	20		89%
3	135	24		82%
4	214	10		95%
5	206	10		95%
6	244	10		96%
7	201	10		95%
8	155	24		85%
9	130	15		88%
10	166	30		82%
11	165	10		94%
12	170	10		94%

Source: own elaboration.

Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged into the aquatic environment. The scheme experienced shows an average suspended solids removal efficiency of 85%, and a maximum of 91%, during the time interval analyzed. In relation to the maximum permissible suspended solids value of municipal wastewater discharges into surface waters, the system complies with the value established in the Dominican Environmental Standard on Control of Discharges to Surface Waters, Sanitary Sewerage and Coastal Waters, as evidenced in Table no 4.

Table no 4: Influential and effluent values of suspended solids.

Suspended solids				
Week	**Influential suspended solids (mg/l)**	**Effluent suspended solids (mg/l)**	**Permissible limits (mg/l)**	**Efficiency**
1	130	12	35	91%
2	120	17		86%
3	110	26		76%
4	260	25		90%
5	120	35		71%
6	350	38		89%
7	110	21		81%
8	140	21		85%
9	250	32		87%
10	130	12		91%
11	190	24		87%
12	110	12		89%

Source: own elaboration.

Knowledge of the nitrogen content in its various forms is of great interest. Thus, for example, when water destined for human consumption presents organic nitrogen, or ammoniacal nitrogen, it is an indication of recent faecal contamination, which is an alert about its danger[7]. In those cases where the control of algae growth in the receiving water bodies is necessary to preserve the intended uses, the elimination or reduction of nitrogen in the wastewater prior to discharge will be necessary. In this sense, the designed scheme presents an average removal efficiency in the total nitrogen parameters of 67%, and a maximum of 80%, for Ammonium Nitrogen, average removal of 86% and maximum 96% during the analyzed time interval.

With reference to the maximum values of Ammonium Nitrogen, and Ammonium Nitrogen and Nitrates, the implemented scheme allows the wastewater treatment plant to comply with the limit values established in the Dominican Environmental Standard on Control of Discharges to Surface Waters, Sanitary Sewerage and Coastal Waters, as shown in Tables no 5-7.

Table no 5: Influential and effluent values of total nitrogen.

Total Nitrogen				
Week	**Influential Total Nitrogen (mg/l)**	**Total nitrogen effluent (mg/l)**	**Permissible limits (mg/l)**	**Efficiency**
1	22.0	7.0	Not normalized	68%
2	23.2	7.2		69%
3	17.0	6.0		65%
4	17.7	7.0		60%
5	20.6	7.0		66%
6	17.9	5.6		69%
7	21.0	6.9		67%
8	8.0	2.0		75%
9	15.1	4.0		74%
10	15.0	3.0		80%
11	12.0	6.0		50%
12	18.3	7.0		62%

Source: own elaboration.

Table no 6: Influential and effluent values of ammonium nitrogen.

Ammonium Nitrogen				
Week	**Influential ammonium nitrogen (mg/l)**	**Effluent ammonium nitrogen (mg/l)**	**Permissible limits (mg/l)**	**Efficiency**
1	9.0	1.0	10	89%
2	12.6	1.6		87%
3	6.0	0.6		90%
4	11.6	1.9		84%
5	12.7	1.2		91%
6	9.2	1.8		80%
7	11.5	2.2		81%
8	10.0	1.2		88%
9	6.6	2.1		68%
10	12.0	1.4		88%
11	9.0	0.4		96%
12	8.3	1.3		84%

Source: own elaboration.

Table no 7: Influential values of total nitrogen, and nitrogen ammonium effluent and nitrates.

Ammonium Nitrogen			
Week	**Influential ammonium nitrogen (mg/l)**	**Nitrogen Ammonium and Effluent Nitrates (mg/l)**	**Permissible limits (mg/l)**
1	22.0	4.2	18
2	23.2	4.1	
3	17.0	1.3	
4	17.7	1.6	
5	20.6	2.1	
6	17.9	-0.3	

7	21.0	3.7	
8	8.0	0.8	
9	15.1	1.9	
10	14.0	1.6	
11	12.0	5.6	
12	18.3	5.7	

Source: own elaboration.

Table no 8: Influential and effluent values of biochemical oxygen demand.

BOD_5				
Week	**Influential$_{BOD5}$ (mg/l)**	**$_{BOD5}$ effluent (mg/l)**	**Permissible limits (mg/l)**	**Efficiency**
1	68	3	35	96%
2	63	7		89%
3	45	8		82%
4	86	4		95%
5	93	4		96%
6	68	4		94%
7	75	3		96%
8	55	15		73%
9	50	5		90%
10	45	6		87%
11	55	3		95%
12	57	3		95%

Source: Prepared by the authors.

The$_{BOD5}$ test is used to measure the organic matter content of both natural and residual water, and is used to determine the approximate amount of oxygen that will be required to chemically stabilize the organic matter present. The implemented scheme presents an average removal efficiency for the chemical oxygen demand of 91%, and a maximum of 96%, during the analyzed time interval. With reference to the maximum allowable COD value of municipal wastewater discharges into surface waters, the system complies with the value established in the Dominican Environmental Standard on Discharge Control to Surface Waters, Sanitary Sewerage and Coastal Waters, as shown in Table no 3.

Knowledge of the phosphorus content of wastewater is of interest, as this element is an essential factor in the life of aquatic organisms. The presence of phosphorus compounds in receptor courses induces algae growth. These significantly affect the quality of water since they can be the origin of a whole sequence of phenomena, since this element is the limitation for the development of these forms of life[7]. The designed scheme presents an average and maximum removal efficiency in the total phosphorus parameters of 61% and 77%, and of 47% and 70% for Orthophosphates during the analyzed time interval. Table no 9 shows the behavior of Total Phosphorus and Table no 10 shows the behavior of Orthophosphates.

Table no 9: Influential and effluent values of total phosphorus.

Total Phosphorus				
Week	**Influential Total Phosphorus (mg/l)**	**Total effluent phosphorus (mg/l)**	**Permissible limits (mg/l)**	**Efficiency**
1	5.0	2.0	Not set	60%
2	7.0	2.2		69%
3	6.0	3.0		50%
4	6.1	2.3		62%
5	10.0	2.3		77%
6	7.3	3.2		56%
7	6.4	2.5		61%
8	6.0	2.0		67%
9	3.8	2.3		39%
10	4.3	2.0		53%
11	6.0	2.0		67%
12	6.2	2.0		68%

Source: own elaboration.

Table no 10: Orthophosphate values of influent and effluent.

Orthophosphate				
Week	**Influential orthophosphates (mg/l)**	**Effluent orthophosphates (mg/l)**	**Permissible limits (mg/l)**	**Efficiency**
1	3.0	2.0	2	60%
2	7.1	2.1		69%
3	5.0	3.0		50%
4	4.5	2.1		62%
5	5.4	2.2		77%
6	4.2	3.0		56%
7	4.4	2.2		61%
8	4.0	2.0		67%
9	3.1	1.8		39%
10	4.0	2.0		53%
11	4.0	2.0		67%
12	3.3	2.0		68%

Source: Prepared by the authors.

The ion concentration is a quality parameter of great importance for both natural and wastewater. The appropriate concentration range for optimal proliferation and development of most biological life is fairly narrow and critical. Waste water with inadequate hydrogen ion concentrations presents difficulties in process treatment and the effluent can modify the concentration of hydrogen ion in natural waters if it is not modified before the water is evacuated[8]. The scheme implemented with reference to the permissible pH values of municipal wastewater discharges in surface waters, complies with the range established in the Dominican Environmental Standard on Control of Discharges to Surface Waters, Sanitary Sewerage and Coastal Waters, as shown in Table no 11.

Table no 11: Influential and effluent values of hydrogen potential.

pH			
Week	**influential pH (mg/l)**	**effluent pH (mg/l)**	**Permissible limits (mg/l)**
1	7.6	7.6	6-9
2	7.4	7.7	
3	7.3	7.7	
4	7	7.1	
5	7.4	7.6	
6	7.1	7.1	
7	7.1	7.0	
8	7.5	7.8	
9	7.2	7.3	
10	6.9	6.7	
11	6.5	6.5	
12	7.3	7.3	

Source: own elaboration.

Dissolved oxygen is necessary for the respiration of aerobic microorganisms, as well as for other life forms. Table no 12 shows the increase in dissolved oxygen present in the effluent of the Rafey sewage treatment plant with respect to the concentration of the influent.

Table no 12: Influential and effluent dissolved oxygen values.

Dissolved Oxygen			
Week	**Influential dissolved oxygen (mg/l)**	**Effluent dissolved oxygen (mg/l)**	**Permissible limits (mg/l)**
1	2.9	5.6	
2	2.3	6.5	
3	0.7	5.9	
4	1.2	5.6	
5	1.4	5.6	
6	1.8	5.3	
7	0.8	5.8	
8	1.0	4.8	
9	3.0	5.7	
10	0.8	5.6	
11	2.3	6.0	
12	1.2	6.0	

Source: Compiled by author

In general, it is established that a concentration of dissolved oxygen in water above 5 mg/l is sufficient for aquatic life.

During the three (3) months of experimentation of the scheme under test, microscopic observations were made of the water samples taken in the process tanks of the PTAR Rafey, in order to identify and classify the characteristic microorganisms that may be found in the activated sludge. The basic groups of Protozoa subject to identification were the Flagellates, Amoebas and Ciliates, because each of these groups plays a specific function in the system and their presence reflects the different physicochemical conditions in the tanks of biological processes.

In the first month of experimentation of the scheme of nitrification and denitrification cycles for the production of biosolids (Table no 13), the presence of flagellates was observed in 5% of the monitored days. This is because flagellates are not abundant when the purification process is working properly. The presence of Euglypha, Arcella, and Euglena was identified in the group of testaceous amoebae that may appear in facilities with good nitrification and low organic load. In the case of the ciliated protozoa in the extended aeration tanks, the most frequent were the Opercularia and Vorticella present in 100% of the monitored days.

Table no 13: Microscopic observation in biological process tank for first month.

Group		**Name**	**Frequency in days**
Protozoa	Ciliata	Phormidun	24%
		Opercularia	100%
		Vorticella	100%
		Acineta tuberosa	10%
		Bear, Water	71%
		Parameciun	14%
		Euplotes sp	62%
		Euplotes harpa	14%
		Coleps hirtus	5%
		Aelosoma sp	10%
	Mastigophora	Cryptomone	5%
	Amebas	Euglena	33%
		Euglypha	90%

		Arcella	48%
Metazoa	57D PHYLUM ROTIFERA	Colurella	71%

Source: own

The presence of ciliated protozoa in the active sludge is of great importance in the process, since they contribute directly to the clarification of the effluent through two actions, which are flocculation and predation, the latter being the most important.

During the first month of experimentation, metazoa were also identified, their presence in activated sludge is less than that of protozoa, especially rotifers, especially colurella in 71% of the monitored days. Rotifers are found in systems with good stabilization and with excess dissolved oxygen. They metabolize solid particles and feed on protozoa and bacteria.

In the second (Table no 14) and third month (Table no 15) of subjection to the nitrification and denitrification cycle scheme for the production of Biosolids, the presence of flagellates was not observed, dominating the group of amoebas (Euglypha, Arcella, and Euglena), and of ciliates standing out with a presence greater than 90% of the days monitored by the Opercularia, Volticela and Euplotes.

Table no 14: Microscopic observation in biological process tank for first month.

Group		**Name**	**Frequency in days**
Protozoa	Ciliata	Opercularia	100%
		Euplotes sp	91%
		Vorticella	95%
		Litonotus	5%
		Acineta tuberosa	9%
		Arcella	5%
		Tardigrados	59%
		Euplotes harpa	91%
		Parameciun	18%
		Phormidun	32%
	Amebas	Euglena	41%
		Euglypha	91%
		Arcella	82%
Metazoa	57D PHYLUM ROTIFERA	Colurella	91%
		Lecane sp	5%

Source: own

Table no 15: Microscopic observation in biological process tank for first month.

Group		**Name**	**Frequency in days**
Protozoa	Ciliata	Opercularia	100%
		Euplotes sp	81%
		Tardigrados	69%
		Acineta tuberosa	25%
		Volticella	94%
		Coleps hirtus	19%
		Aelosoma sp	6%
		Phormidium	38%

		Parameciun	6%
		Litonotus	6%
		Oxytrichia	13%
	Amebas	Euglena	13%
		Euglypha	75%
		Arcella	75%
Metazoa	57D PHYLUM ROTIFERA	Colurella	75%

Source: own

IV. Conclusions

The objective of this research is to design and validate a scheme that contemplates nitrification and denitrification for wastewater treatment in the Dominican Republic. The results have shown that the scheme designed is adequate to provide water with the quality characteristics required by Dominican standards for water leaving the treatment plants (effluent). In this sense, all the parameters analyzed in the influential of the PTAR Rafey have improved the quality of its polluting load at the outlet of the treated water (effluent), always being located below the permissible values in the Dominican standards. In future research, it should be analyzed whether the wastewater treatment scheme proposed by this research improves the nutritional characteristics of the sewage sludge that is generated in the process.

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