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Filter Efficiency with Red Rock as Post-Treatment of Stabilization Pond Effluent, Prototype Case Study San Marcos, Carazo, from April to September 2019

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Abstract

An experimental unit was built which was located in the vicinity of the domestic wastewater treatment plant of the Municipality of San Marcos in the Department of Carazo. Said unit consisted of two welded metal barrels with a total height of 1.8 m and a diameter of 0.90 m, likewise, this unit comprised three functional zones; the first or input area composed of a collection unit, a driving unit, a flow control unit, and two distribution units; the second or packed zone, which is the axis of the system because it is there where bacterial growth takes place and where the removal of organic matter takes place; and an outlet composed of PVC pipe [1]. The main objective of this work was to determine how efficient a rocky filter turns out to be, using stabilization pond effluent as a post-treatment unit using red concrete as a filter medium. The study consisted in carrying out laboratory tests on water samples taken from the influent and effluent of a filter made up of red rock, as a filter medium, in order to determine the percentage of organic matter removal efficiency that it has used a hydraulic retention time of 19 hours, 15 hours, and 12 hours [2]. Among the aspects to be considered in the experimental study was the characterization of the effluent from the treatment system of San Marco, Carazo, to determine the quality of water that will be of interest to the study [3]. In this stage, four composite samplings were carried out, two of 12 hours and two of 24 hours, in which physical, chemical, and microbiological parameters were analyzed. Likewise, to determine the efficiency of the filter, the same parameters considered in the characterization of the lagoon effluent were analyzed, obtaining removal efficiencies of up to 55.53% in organic matter, and 64.60% in suspended solids for a hydraulic retention time of 19 hours; In the same way, the efficiency of the filter was carried out for retention times of 15 hours and 12 hours, in which organic matter removals of 67.84% and

56.59% and 82.77% and 77.51% in total suspended solids were found, respectively.

Keywords

Design, Filter, Flow, Flocs, Transport, Water Quality

1. Introduction

Water is one of the most fundamental resources and, together with air, land, and energy, constitutes the four basic resources on which the development of the vine is based. Of all the water that reaches our homes, a small fraction is for drinking, and the rest is used for washing, bathing, flushing toilets, cooking, cleaning, and others. A large percentage of this water used in the home is wasted or goes as used water, therefore, to maintain a clean environment and excellent public health, this used water must leave the homes and be taken to another place. Hence, the adequate treatment of water and its subsequent reuse for multiple uses is necessary to promote sustainable consumption and environmental regeneration [4].

In Nicaragua [3], most of the treatment systems consist of stabilization ponds, however, due to the increase in organic discharges from the water they receive, the design is no longer suitable for proper treatment, currently, the effluent resulting from treatment does not comply with the standards, generating environmental problems and risks to human health. Based on the foregoing, the study analyzes the efficiency of an anaerobic rocky membrane filter as a post-treatment mechanism for effluents from stabilization ponds, through a pilot practical case of experimentation located in the treatment system of San Marcos, Carazo.

2. Methodology

2.1. Geographic Location of the Study

The experimental study was carried out on the grounds of the La Reforma farm, adjacent to the facilities of the wastewater treatment plant that consists of stabilization ponds and is managed by the Nicaraguan Aqueduct and Sewer Company (ENACAL) located in the municipality of San Marcos, in the department of Carazo. See Table 1.

2.2. Type of Study

The study is located in the category of cross-sectional prospective experimental research, since it was determined how efficient vertical flow red rock filters are as post-treatment of stabilization pond effluents based on the fact that it discharges its waters with inadequate quality; and at the same time, the study is developed in a certain period of time.

On the other hand, the study is multidisciplinary with a quantitative approach

Table 1. General data of the municipality of San Marcos.

Municipality	Saint Mark
Department	Carazo
Area	108 km^2
coordinates	San Marcos is located between the coordinates 11˚54' north latitude and 86˚12' west longitude, its head is located 43 kilometers from Managua
Limits	To the north: Municipality of La Concepción; To the south: Municipality of Diriamba and Jinotepe; To the east Municipality of Masatepe; To the west Municipality of San Rafael del Sur
Additional data	Total population: 25521.00 inhabitants; Urban Population: 10053.00 inhabitants (39.4%); Rural Population: 15468.00 inhabitants (60.6%)

Source: self made (2019), data obtained from the Municipal Mayor's Office of San Marcos.

because it covers various areas of scientific knowledge such as chemistry, biology, microbiology, civil, sanitary and environmental engineering, in addition to collecting and analyzing data.

2.3. Execution Time

The investigation was carried out during a period of thirteen months, of which two weeks were used to characterize the effluent from the stabilization pond, sixteen weeks for sampling and laboratory analysis to determine the efficiency of the filter, which began its operation on June 2, 2019, and the rest of the time for collecting theoretical information, obtaining resources and preparing a report.

2.4. Universe

The universe for carrying out the study included the wastewater of domestic origin treated in the stabilization ponds of the San Carlos, Carazo plant.

2.5. Sample

The sample to determine the efficiency of the red rock membrane filter consisted of a certain amount of domestic wastewater collected from the effluent of the treatment system.

2.6. Inclusion Criteria

All those wastewaters that:

1) Be of domestic origin;

2) It has been previously treated in the stabilization ponds of San Marcos, Carazo.

2.7. Exclusion Criteria

All water that does not meet the inclusion criteria will be excluded.

2.8. Sampling

The sampling of wastewater and receiving streams constitute one of the fundamental aspects in any program that aims to reduce the degree of contamination in natural resources. Therefore, for the evaluation of the operation of this system it was necessary to previously propose a careful sampling program considering the following aspects:

Sample Volume

Taking into account the possibility of repeating analyzes with doubtful results; the total volume was 12 liters.

For the composite sample, it was necessary to consider the average flow rate, the hourly flow rates, the sampling time and the total amount of sample to determine the volume of sample to be collected per hour using the following equation [5]:

$$\forall_{mh} = \frac{Q_H * \forall_{muestra}}{Q_{prom} * T_m} \quad (1)$$

where:

$\forall_{mh}$ = Volume of the hourly sample;

Q_H = Hourly flow;

Q_{avg} = Average Flow;

$\forall_{sample}$ = Sample volume;

T_m = Sampling time.

Type of Sample

The type of sample that was made was composed and proportional to the flow for the characterization of the residual water of the current system. For the determination of the efficiency, simple samples were taken.

Sampling Frequency

For the characterization of the effluent wastewater from the existing treatment system, 4 rounds of sampling were carried out for two weeks, of which 2 rounds of 12 hours and 2 of 24 hours. For the efficiency analysis, simple samples were carried out for 18 weeks.

2.9. Analysis Unit

The operational efficiency of the red rock membrane filter system was analyzed as a pro-treatment system in the maturation lagoon of the city of San Marcos, Carazo; in the period of sixteen weeks (June-September) of 2019, through a pilot scale unit, which began its operation on June 2, 2019

2.10. Description of the Pilot Scale Experimentation Unit

In general terms, the upflow red rock membrane filter is composed of three functional zones: see **Figure 1**, [6] [7].

- Entrance area: which allows a uniform distribution of the residue in the filter medium.

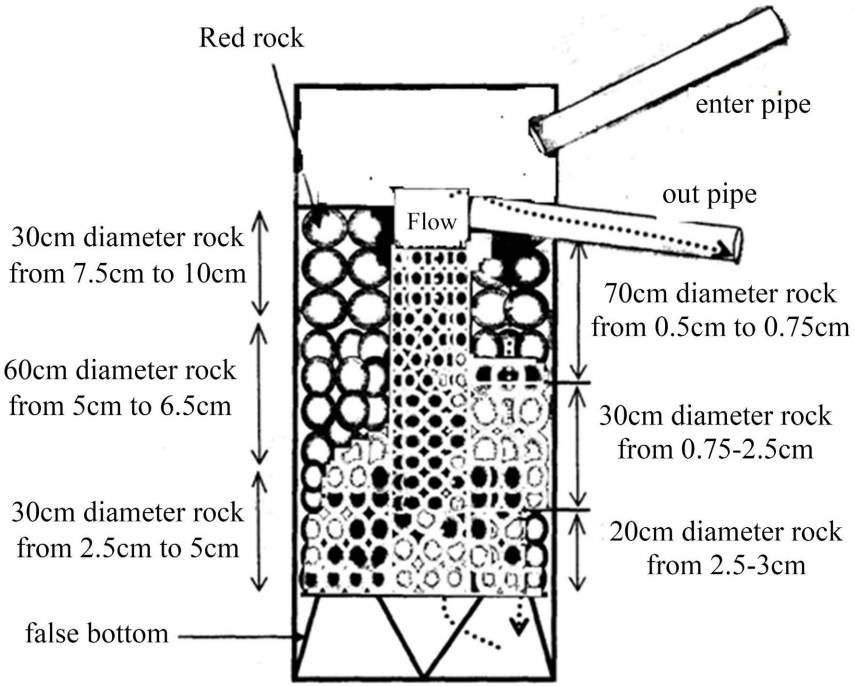

Figure 1. Schematic representation of the filter, with its components. Source: self made (2019).

- Packed area: which includes the filter medium and the main bacterial growth occurs.
- Starting area.

2.11. Variables

To characterize the effluent from the stabilization pond and determine the efficiency of the filter, the following variables and subvariables were taken into account:

- Flow;
- Hydraulic Retention Time;
- Volumetric Organic Load;
- Biochemical quality of the water: pH, DBO and DQO;
- Physical quality of the water: Total Solids, Total Dissolved Solids and Total Suspended Solids;
- Bacteriological quality of the water: Thermotolerant Coliform.

2.12. Material and Method

Information Collection Method

For the preparation of this research, an exhaustive review of the literature related to the purpose of the work was carried out, for this review constant visits to documentation centers such as the Library of the National Autonomous University of Nicaragua, Managua (UNAN-Managua; Library of the Nicaraguan Aqueduct and Sewer Company (ENACAL), Center for Research and Environmental

Studies (CDOC-CIEMA) and Chemical Engineering of the UNI, among others, as well as specialized institutions related to the subject, such as the Institute of Geology and Geophysics (CIGEO-UNAN-Managua), Nicaraguan Institute of Territorial Studies (INETER), Center for Research on Aquatic Resources (CIRA-UNAN-Managua), Engineering, Development and Research IDISA, Batahola Campus of the Mayor's Office of Managua.

For the study, laboratory analyzes were carried out on samples collected at the inlet and outlet of the filter, transferred to the Center for Research in Aquatic Resources (CIRA-UNAN-Managua).

Analysis of the Information

The data obtained in the laboratory analyzes of the collected samples were studied, through the realization of tables and graphs with the application of tools from the Microsoft Excel and Microsoft Word programs.

Materials

For the preparation of the site where the unit was located:

- Machetes, shovels, pickaxe, buckets, rake, bar.

For the pilot unit we used:

- 2 metal barrels, stop valves, cement, Teflon, red rock, pliers, 1/16 wire, 1 1/2" steel nails, 1/2" brush, steel rod, anticorrosive paint, 1/2" PVC pipes, PVC elbows 1/2", welding, 1/2" PVC sleeves, sandpaper, scoop, wood, sponge, smooth zinc, 1/2" PVC tee.

For the collection of the sample, the following was used:

- Sterilized glass jars, sterilized jars for bacteriological samples, plastic gallons for composite samples, graduated ruler, control table, 5 gln and 3 gln buckets, flashlights, latex surgical gloves, 250 ml and 500 ml plastic cylinders, soap liquid antibacterial, pizeta, plastic droppers, gloves, thermos, ice, tape measure, thermometer, notebook, rubber boots, stopwatch, Conductivity meter, paper towel, sulfuric acids, distilled water.

3. Results

Averages obtained from the analysis of the samples collected for the characterization of the lagoon effluent. See Table 2 & Table 3.

Averages obtained from the analysis of the samples collected to determine the efficiency of the red rock membrane filter according to the TRH used. See Tables 2-6.

Table 2. Average parameters for characterization of the lagoon effluent.

Parameter	Average
Temperature ˚C	28.40
Flow l/s	4.7
Conductivity ($\mu s \cdot cm^{-1}$)	685.52

Source: self made (2019).

Table 3. Average chemical parameters.

Parameter	Concentration	Decree 33 - 95	
	Effluent	To be poured	For irrigation
DQO mg·l^{-1}	253.95	220	200
DBO mg·l^{-1}	160.12	110	120
ST mg·l^{-1}	589.75	no reference	no reference
STD mg·l^{-1}	466.50	no reference	no reference
STS mg·l^{-1}	123.25	100	120
pH (units of pH)	8.58	6 - 9	6.5 - 8.5
Thermotolerant Coliform NMP/100 ml	3.3E+04	1000 - 5000	1.00E+03

Source: self made (2019).

Table 4. Characterization of the sample with the red rock membrane filter for TRH 19h.

Parameter	Concentration		%	Decree	
	Afluent	Effluent	Removal	To be poured	For irrigation
DQO mg·l^{-1}	345.21	153.52	55.53	220	200
DBO mg·l^{-1}	180.02	73.93	58.93	110	120
ST mg·l^{-1}	587.64	435.07	25.96	no reference	no reference
STD mg·l^{-1}	354.86	352.57	0.65	no reference	no reference
STS mg·l^{-1}	232.86	82.43	64.60	100	120
pH (unids of pH)	8.58	8.18	Óptimo	6 - 9	6.5 - 8.5

Source: self made (2019).

Table 5. Characterization of the sample with the red rock membrane filter for TRH 15h.

Parameter	Concentration		%	Decree	
	Afluent	Effluent	Removal	To be poured	For irrigation
DQO mg·l^{-1}	466.06	149.89	67.84	220	200
DBO mg·l^{-1}	102.49	53.15	48.14	110	120
ST mg·l^{-1}	873.83	457.50	47.64	no reference	no reference
STD mg·l^{-1}	382.50	372.83	2.53	no reference	no reference
STS mg·l^{-1}	491.33	84.67	82.77	100	120
pH (unid of pH)	8.64	8.07	Óptimo	6 - 9	6.5 - 8.5

Source: self made (2019).

Table 6. Characterization of the sample with the red rock membrane filter for TRH 12h.

Parameter	Concentration		%	Decree	
	Afluent	Effluent	Removal	To be poured	For irrigation
DQO mg·l^{-1}	183.53	79.67	56.59	220	200
DBO mg·l^{-1}	64.08	26.61	58.47	110	120

Continued

ST mg·l^{-1}	572.80	410.0	28.42	no reference	no reference
STD mg·l^{-1}	321.70	353.60	−9.92	no reference	no reference
STS mg·l^{-1}	251.20	56.50	77.51	100	120
pH (unids of pH)	7.73	7.62	Óptimo	6 - 9	6.5 - 8.5

Source: self made (2019).

4. Analysis of the Results

4.1. Characterization of the Effluent from the Stabilization Pond

After processing the information from the results of the laboratory tests, it was found through the characterization carried out for two weeks to the tributary of the stabilization ponds, that the existing system in San Marcos discharges an average amount of water of 4.70 l/s, equivalent to 406.08 m^3/day, with a temperature of 28.40˚C and an electrical conductivity of 685.52 µs·cm^{-1}.

Likewise, it can be affirmed that none of the parameters analyzed complies with the standards established by ENACAL, with the exception of pH. For example, as can be seen in the DQO, an average of 253.95 mg·l^{-1} was obtained, much higher than that allowed to be discharged (220 mg·l^{-1}) and to be used in irrigation (200 mg·l^{-1}).

Similarly, in DBO it exceeds with approximately 40 mg·l^{-1} the norms of 110 mg·l^{-1} to be discharged and 120 mg·l^{-1} for irrigation.

On the other hand, a concentration of total solids (589.75 mg·l^{-1}) was found, of which the majority are dissolved solids (466.50 mg·l^{-1}) and the rest are suspended solids (123.25 mg·l^{-1}).

4.2. Red Rock Membrane Filter Efficiency

After the characterization stage, the purification capacity of the red rock membrane filter was determined, installing said unit during the month of May and starting on June 2, 2019. When taking the samples and analyzing the results, the following reasoning is presented:

Evaluating the pH ranges reached, it is observed that they are quite close to the standards and provide conditions for biological processes to occur within the filter, being located in the pH range between 6 to 9. With these conditions, removals of each parameter were achieved, achieving that the values are below those allowed to be used in irrigation and to be discharged into a receiving medium.

With the results, it can be seen that there is a good purification process, reflected in the DBO and DQO values that decrease their value from 345.21 mg·l^{-1} and 180.20 mg·l^{-1} to 153.52 mg·l^{-1} and 73.93 mg·l^{-1} respectively for TRH hours.

In the same way, it occurs in the retention time of 15 hours, in which average values were obtained at the input of 466.66 mg·l^{-1} of DQO and 102.49 mg·l^{-1} of DBO, with an output concentration of 149.89 mg·l^{-1} of DQO, and 53.15 mg·l^{-1} of

DBO.

For the retention time of 12 hours, the DQO values decrease from 183.53 $mg{\cdot}l^{-1}$ to 79.67 $mg{\cdot}l^{-1}$ and the DBO from 64.08 $mg{\cdot}l^{-1}$ to 26.61 $mg{\cdot}l^{-1}$.

Likewise, in the suspended solids, values were reached below the limits stipulated in the regulations of Decree No. 33-95, article 23, regardless of the retention time.

Likewise, the average removal percentages achieved for each parameter are reflected. It is observed that the removal percentages for most of the parameters are above 50%.

In the dissolved solids, low percentages of removal are found because these are micrometric particles that cannot be retained by the filter medium and from time to time their value increases due to the fact that the retained suspended solids settle, also affecting the wear of the medium filter.

According to the results obtained in the study, the DQO removal in the red rock membrane filter is 67.84% on average for the hydraulic retention time of 15 hours. However, it is convenient to analyze the individual behavior during the entire period of the experiment to understand the results, as expressed below.

4.3. Analysis of Each Parameter Evaluated during the Efficiency Determination Stage of the Red Rock Membrane Filter

pH

It is notorious that the pH values reached in the filter effluent remain in the range of 7 to 9 pH units, which is within what is allowed according to Nicaraguan regulations for discharging treated domestic water. With this it is affirmed that from the first day of operation the filter presented the conditions with respect to this value so that the growth of the microorganisms that would carry out the decomposition of the matter could take place. Likewise, it is noted that this parameter did not vary much when changing the hydraulic retention time.

DQO

With respect to this parameter, it can be seen that the filter has worked well in the removal of organic matter, since it is possible to observe that after just one day of operation, a removal efficiency of 29.41% was obtained, increasing with the advance, of its operation, achieving up to a percentage of 73.33% one month after starting its operation for an influent DQO of 689.22 $mg{\cdot}l^{-1}$, which indicates that it was one of the highest loads for the retention period of 19 hours.

Regarding the TRH of 15 hours, it is evident that the DQO in the effluent remains well above the 200 $mg{\cdot}l^{-1}$ that is required by the standards with loads greater than 200 $grCODm^{-3}d^{-1}$ and up to 700 $grDQOm^{-3}d^{-1}$, reducing at lower DQO values of 200 $mg{\cdot}l^{-1}$, as can be seen in the results table, efficiency of up to 85% in organic matter removal.

For the 12-hour TRH, DQO values of less than 100 $mg{\cdot}l^{-1}$ were obtained, achieving efficiency of up to 60% for values less than 250 $mg{\cdot}l^{-1}$. These tributary loads have presented low concentration values because their samples were collected during the periods of greatest rain that occurred at the end of August and

September, which caused the dilution of the organic load discharged by the lagoon system.

It can be affirmed that the filter works better with DQO values greater than 300 $mg \cdot l^{-1}$ demonstrated for TRH of 19 hours and 15 hours, reaching better efficiencies in the 15-hour period of up to 67%.

DBO

In this part, as well as the DQO, a good removal was obtained, because the filter was not expected to start the removal process very quickly, since no inoculation process was carried out, this had a value of 22.50% at a day of operation increasing in the same way up to a value of 78.75% efficiency with a load of 300 $mg \cdot l^{-1}$ in influent DBO for a TRH of 19 hours with effluent values below 100 $mg \cdot l^{-1}$.

Likewise, it is evident that using a TRH of 15 hours, DBO values remain below 100 $mg \cdot l^{-1}$ and removals of up to 50% are obtained for high volumetric organic loads calculated up to 700 $grDQOm^{-3}d^{-1}$ for the influente.

Similarly, when using a TRH of 12 hours, results of up to 80% efficiency were obtained with effluent values less than 50 $mg \cdot l^{-1}$ for influent concentrations less than 100 $mg \cdot l^{-1}$.

According to the above, it can be affirmed that the filter works very well, obtaining a quality of water with the capacity to be discharged to a receiving body without affecting the environment so much, according to what is stated in decree 33 - 95. Better results were obtained for TRH of 19 hours because the influent values were higher and in the effluent they were kept below 100 $mg \cdot l^{-1}$.

Total Solids

It is evident that a large number of solid substances, composed of suspended and dissolved particles, reach the filter, in which the values are above 300 $mg \cdot l^{-1}$ regardless of the TRH used, achieving efficiency of up to 36% for TRH of 19 hours, 70% for TRH of 15 hours and 60% for TRH of 12 hours.

Total Dissolved Solids

As for the dissolved solids, the filter does not present very good efficiency to retain them since they are of microscopic size, managing to cross the barrier or filter medium.

From the above, a behavior of the STDs is appreciated, where values of 9.05% are obtained in removal for the TRH of 15 hours, with concentrations in the tributary greater than 280 $mg \cdot l^{-1}$.

This same parameter presents even negative values, in percentages of efficiency in some cases because its value increases in the effluent as a result of the dissolution of the suspended matter retained by the rocks.

Suspended Total Solids

In this aspect, the filter removes a large amount of suspended particles through the retention of this matter whose size is larger and can be adsorbed by the filter medium, that is, the red rocks used, whose porosity allows the action of this process.

The efficiency obtained was very good, since it is observed that the values in the effluent were reduced to values less than 120 $mg \cdot l^{-1}$, which is within what is allowed by the regulations for the control of pollution from the discharges of domestic, industrial, and agricultural wastewater that pose a maximum value to be used in irrigation of 120 $mg \cdot l^{-1}$ and 100 $mg \cdot l^{-1}$ to be discharged into a receiving medium.

5. Conclusions

The results obtained in the stage of characterization of the effluent water from the stabilization pond system of San Marcos, Carazo, show that the water discharged by this system is not very suitable to be discharged into a receiving medium or to be reused through irrigation, since the results obtained present values above those required by Nicaraguan standards, this plant pours an average flow of 4.7 l/s, said water has an average total solids content of 589.75 $mg \cdot l^{-1}$, dividing into Total Dissolved Solids of 466.50 $mg \cdot l^{-1}$ and Total Suspended Solids of 123.25 $mg \cdot l^{-1}$.

Regarding the parameters that determine the degree of Biochemical contamination, the waters present a DQO of 253 $mg \cdot l^{-1}$ and DBO of 160.12 $mg \cdot l^{-1}$, so this water needs post-treatment to reduce its contamination levels.

For this reason, the rocky filter studied would be a viable option for this post-treatment since it is evidenced through the experiment that this method has very good results in removing organic matter, even without having been inoculated prior to its operation.

The efficiency of filters in load removal is associated with biological activity strongly related to temperature and mainly by the variable Hydraulic Retention Time, which refers to the average time a liquid remains inside the filter.

To analyze the removal efficiency of this filter, retention times of 19 hours, 15 hours, and 12 hours were used. Of which better results were obtained when using the TRH of 15 hours, since this period the highest loads were obtained and the effluent maintained the values below the maximum required in Decree 33-95 to be discharged and used in irrigation.

For the 19-hour TRH, the average volumetric load with which the filter operated was 438.01 grDQO m^3 day^{-1} and a flow rate of 0.00.42 l/s, obtaining removal averages of 55.53% in DQO, 58.93% for DBO and 64.60% for Suspended Total Solids.

Then, when using the TRH of 15 hours, the average volumetric load with which the filter operated was 760.29 grDQO m^3 day^{-1} and a flow rate of 0.0054 l/s, obtaining removal averages of 67.84% in DQO, 48.14% for DBO, and 82.77% for Suspended Total Solids.

Likewise, for the TRH of 12 hours, the average volumetric load with which the filter operated was 362.14 grDQO m^3 day^{-1} and a flow rate of 0.0066 l/s, obtaining removal averages of 56.59% in DQO, 58.47% for DBO, and 77.51% for Suspended Total Solids.

On the contrary, regarding the removal of Total Dissolved Solids and Thermotolerant Coliforms, this type of treatment was not very suitable for the retention time and loads used, since very high concentrations were obtained in their effluent.

Regarding the filter medium, it is stated that the red concrete or red rock can be a filling material to be used in the rock filter, since it has good characteristics to retain and remove the organic matter present in the domestic wastewater treated in the stabilization ponds.

Gratitude

My thanks go first to my mother Beatriz Picado, who gave me life, who knew how to train and educate me, and who, with her spiritual guidance, has taught me a lot to face all obstacles with Faith and Reason. Doña Beatriz has been a symbol of improvement.

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My wife, the most beautiful of all women Lisseth Blandon Chavarria.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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