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Design and characterization of a prototype anaerobic reactor for domestic wastewater treatment using fixed biomass

Diseño y caracterizacion de un reactor anaerobio prototipo para tratamiento de aguas residuales domésticas utilizando biomasa fija

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Abstract

In developing countries, the RAFA (Anaerobic Upflow Reactor) reactor stands out as a viable alternative in wastewater treatment. In addition, biofilters are used in the biological reactors that have the objective of biofilm formation, by means of which effluents of better quality are obtained. An anaerobic reactor of 140 Liters was evaluated for the treatment of domestic wastewater. Granular activated carbon and cellulose fiber filters were placed outside. After the stabilization of the reactor (3-6 months), different volumes corresponding to 3, 5 and 7 liters / day of residual water were evaluated, with hydraulic retention times (HRT) of 47, 28 and 20 days, respectively. Percentages of reduction of BOD5, COD, SST and fecal coliforms were obtained for the 3 effluents. It was obtained for 3 liters / day: 90%, 66%, 90% and 99.9%. For 5 liters / day: 93%, 71%, 90% and 99.9%. For 7 liters / day: 80%, 65%, 91% and 99.9%. With these results and comparing them with the NOM-003-Ecol-1997. It is concluded that the treated wastewater can be reused to be reused in public services.

Wastewater, Hydraulic retention time, Biofilm, Biological reactor

Resumen

En los países en desarrollo, el reactor RAFA (Reactor anaerobio de flujo ascendente) resalta como una alternativa viable en el tratamiento de aguas residuales. Además, dentro de los reactores biológicos se emplean soportes que tienen como objetivo la formación de biopelícula, mediante la cual se obtienen efluentes de mejor calidad. Se evaluó un reactor anaerobio de 140 Litros para el tratamiento de aguas residuales domésticas. En el exterior se colocaron filtros de carbón activado granular y fibra de celulosa. Despues de la estabilización del reactor (3-6 meses), fueron evaluados diferentes volúmenes que correspondieron a 3, 5 y 7 Litros/dia de agua residual, con tiempos de retención hidráulica (TRH) de 47, 28 y 20 días, respectivamente. Se obtuvieron porcentajes de reducción de DBO_5, DQO, SST y coliformes fecales para los 3 efluentes. Se obtuvo para 3 Litros/dia: 90%, 66%, 90% y 99.9%. Para 5 Litros/dia: 93%, 71%, 90% y 99.9%. Para 7 Litros/dia: 80%, 65%, 91% y 99.9%. Con estos resultados y comparándolos con la NOM-003-Ecol-1997. Se concluye que se puede reutilizar el agua residual tratada para que se reusen en servicios al publico.

Aguas residuales, Tiempo retención hidráulica, Biofilm, Reactor biológico

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Introduction

This work presents the evluation of a prototype for the treatment of domestic wastewater through anaerobic digestion, which does not use any type of energy and easy maintenance, which makes the prototype sustainable.
Introducción

Problem in the availability of water

Globally, the volume of renewable water per capita has decreased by 40% in the last 22 years [1]. This is a consequence of significant population growth and changes in lifestyles due to rapid economic growth that generate high demands for water to supply agriculture, industry and cities [2, 3] In addition, the inadequate treatment of the large volumes of water generated by the different economic sectors has caused diseases and environmental pollution [4]. In addition, the lag in municipal wastewater treatment infrastructure in most countries of the Latin American and Caribbean region is a matter that has not received due attention from the competent authorities. In the case of wastewater collection and drainage systems that do not have a treatment plant, a common situation in developing countries, the wastewater is discharged directly into the natural environment (body of water or soil). With a UASB type anaerobic reactor fed with typical municipal wastewater, removal efficiencies in Chemical Oxygen Demand (COD) of the order of 60 to 70% and biochemical oxygen demand (BOD_5) of 70 to 80% can be achieved [5].

Anaerobic wastewater treatment

In anaerobic systems, bacteria, both strict and facultative anaerobic, are involved; which, through a series of stages and in the absence of oxygen, degrade organic compounds, producing methane and carbon dioxide, mainly.

Anaerobic digestion is carried out in four successive stages. In the first stage, called hydrolysis, complex organic substrates are degraded into soluble monomers. In the second stage, known as acidogenesis, soluble monomers are transformed into organic acids, alcohols, carbon dioxide and hydrogen. In acetogenesis, organic acids are transformed into acetic acid, hydrogen and carbon dioxide.

Finally, in methanogenesis, methane is produced in two ways: the first from the degradation of acetic acid and the second, through the reaction between carbon dioxide and hydrogen produced in the previous stages. Methanogenesis is the slowest stage and determines the overall dynamics of the process; likewise, it is the most sensitive to changes in operating conditions. Therefore, it is considered as the limiting stage and the most interesting from the point of view of automatic control. Thus, this type of process brings benefits in the environmental sector and in the energy sector. The hypothesis raised in the present work is the effect of the application of hydraulic retention time conditions in a UASB type reactor and the interaction of anaerobic microorganisms fixed in the form of a biofilm in a polymeric material, which will reduce the organic load of domestic wastewater.

Some requirements of anaerobic systems in general

The start-up period of anaerobic reactors is a critical and relatively slow stage because a sufficient and balanced microbial population must be developed that often determines the efficiency of reactor operation. Biomass activity depends on many factors; in relation to micronutrients, one's deficiency can limit the biological process. Anaerobic digestion is very sensitive to certain parameters and certain operating conditions, such as pH, temperature, overloads, etc. [7, 8,9]. The growth rate is approximately doubled with an increase of 10°C until the optimum temperature is reached. The typical optimal temperature ranges for bacteria are: 12-18 °C for psychrophilic bacteria, 25-40 °C for mesophilic bacteria and 45-65 °C for thermophilic bacteria. In the case of pH, methanogen organisms effectively work between pH range of 6.5-8.2, with an optimal pH of 7.0. Although it has been shown that the optimal pH range for maximum gas performance is 6.5- 7.5 [10].

Importance of supports for the formation of biofilm in wastewater treatment

Currently, bioreactors with continuous biomass mixing have been built. In addition, they have a retention time based on organic load and inflow rate.

However, this can be a problem because active bacteria, which could be used for wastewater treatment, can leave the reactor causing longer retention times and a decrease inactive microorganisms. To solve this problem, immobilization of bacteria on a solid surface is necessary in order to increase the contact surface in bioreactors.

Due to the formation of biofilms, the hydraulic retention time is independent of the cell retention time. In this way the washing effect is decreased in the bioreactor and biogas production increases [11]. A biofilm is an association of microorganisms attached to a surface, which are trapped within an extracellular polymeric substance [12]. Biofilms have the capacity for the effective elimination of organic compounds and the production of methane [13,14].

The importance of using plastic (such as PET) when employing it as a support material for water treatment is mentioned below: Plastic is used as an indispensable material for modern life. Plastics production has increased production from 0.6 million metric tons in 1950 to 2.5 million tons in 2010, with an average annual growth of about 10%.

Due to human neglect, plastics are found in rivers and oceans. Plastics in the ocean are thought to be increasing. Lightweight plastics such as polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and foamed polystyrene (PS) are frequently found on the ocean surface around the world. Ingestion of plastics by marine animals has been widely reported.

With regard to the use of plastics, the vast majority of researchers have found that microorganisms are incorporated much faster on hydrophobic surfaces such as Teflon and other plastics than on hydrophilic supports [15].

The objective of the work is to develop an anaerobic system for the reduction of the organic load in domestic wastewater by fixing microorganisms in the form of a biofilm in the PET support.

Methodology

Conditioning of the UASB type reactor

The design of the prototype was carried out as shown in Figure 1. Subsequently, the 140-liter UASB type reactor was built, as shown in Figure 2. 15 PET columns were placed at the bottom of the reactor. For the formation of the PET columns, the 0.5, 1 and 2 liter bottles were collected and cut from the base. In addition, a cellulose filter (acting as a solid-liquid separator) and a lid were placed on top to completely cover the reactor. A granular activated carbon filter and a cellulose fiber filter were attached to the outside of the reactor. The prototype consists of influent inlet tubes (raw wastewater), effluent outlet (treated water), sludge meter and sludge purge. The prototype was operated outdoors at room temperature.

Physicochemical characterization of the influencer

Within the adaptation and growth phase, 3 random samples of the influencer were taken (which were carried out in triplicate), in 3 different months and physicochemical tests were carried out in the Hydraulics Laboratory of the Cerro de las Campanas Campus of the UAQ. It was based on the methodologies proposed in NOM-003-SEMARNAT-1997 to perform the following analyses: Fecal coliforms (C.F.), Helminth Eggs (H. H), Fats and Oils (G and A) and Total Suspended Solids (SST). For the determination of the parameters, they were sent to a certified laboratory for analysis.

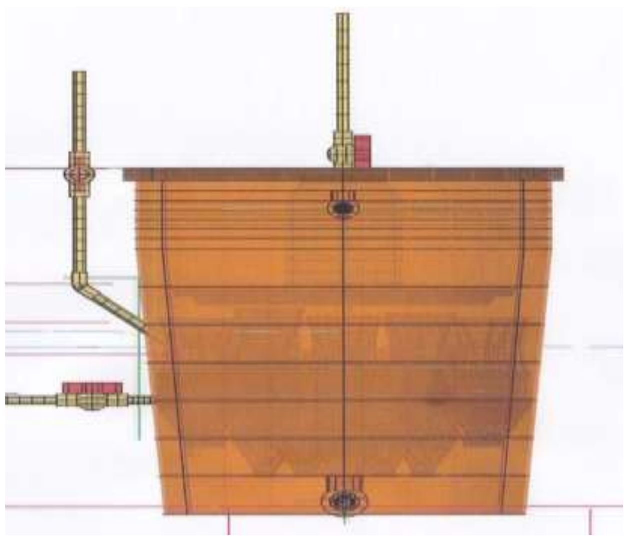

Figure 1 Design of the UASB reactor prototype

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Stabilization of the UASB type system

Initially 40 liters of sludge from a storage pit were introduced into the interior of the UASB reactor. During a period of 3 months the reactor was fed with 1 Liter of wastewater per day, after this time it was proceeded for another 3 months to feed the reactor with 2 Liters of wastewater per day for acclimatization, adaptation and growth of the sludge (the wastewater came from the carcamo of the aerobic water treatment plant of the Multidisciplinary Building Campus Airport of the UAQ). The measurement of the volume of sludge was carried out in a 1 liter specimen to see the growth, the pH value and temperature during this period was also obtained. The turbidity of the treated wastewater was obtained to check the stabilization of the system during this period (1 time each month), in order to proceed to the variation of the flow of the influent.

Figure 2 Construction of the prototype of the UASB type reactor with 2 filters placed on the outside of the reactor (cellulose and granular activated carbon filter)

Analysis of the flow variation of the influent (obtaining the physicochemical analyses of the 3 flows)

Once the system was stabilized, the flows of the influent were varied, where 3 volumes were tested, which corresponded to 3, 5 and 7 liters of wastewater per day. Hydraulic retention times (HRT) were 47, 28 and 20 days respectively. Each volume was added per day until first reaching the HRT of 47, then that of 28 and 20 days respectively to obtain each effluent (3, 5 and 7 liters per day). After each HRT of each volume, 9 effluents corresponding to each flow rate (3, 5 and 7 liters per day) were sampled to perform the physicochemical analyses based on NOM-003-SEMARNAT-1997.

Fixation of the biofilm to the PET and its respective analysis by Scanning Electron Microscopy

After the treatment of the 3 effluents and once it was possible to visually observe the anaerobic sludge adhered to the PET support as shown in Figure 3.

The evidentiary analysis of the fixation of the biofilm was carried out. This analysis was performed by Scanning Electron Microscopy, where small pieces of PET were cut, as shown in Figure 4, which were taken for analysis at the Center for Applied Physics and Advanced Technology (CFATA), Electron Microscopy Laboratory of the UNAM Juriquilla campus located in Juriquilla, Querétaro.

Figure. 3 Adhesion of the sludge visually to the PET material. To the PET columns inside the reactor after 6 months of acclimatization

Figure 4 Trimmed pieces of PET columns

Results

Physicochemical characterization of the influencer

The physicochemical characterization of the influencer in the 4 different samples is shown in Table 1. These results determined the characteristics of the wastewater during the treatment and in this way to be able to compare with the effluents after the treatment (which will be mentioned later), in such a way it was possible to determine the efficiency of the treatment in the anaerobic system. The pH and temperature conditions of the influent in the different samples were in a pH range of 7.0 to 8 and Temperature range of 15 to 26 °C.

No. sample	Fecal Coliforms NMP/100 mL	Fats and oils mg/L	SST mg/L	BOD_5 mg/L	H H (h/L)
Prom.Total4 muestreos	≥2,400,000	3.3	299	270.3	<1

Table 1 Average results of chemical analyses of the influencer

Stability of the UASB type system.

In a period of 3-6 months, the system was stabilized. It was observed that the supernatant was clarified and no scattered flocs were observed in it, which indicated that it had changed from scattered to flocculent mud. What reinforced the above was the comparison that was made in a sampling obtained inside the reactor with respect to that of the influent. The pH and temperature conditions during the selection stage were: pH between 7.0 - 8 and temperature range between 10 - 20 °C. The results of turbidity in 6 different months are shown in Table 2, both of the influent and the effluent (samples obtained at random), which corroborated the stabilization stage of the anaerobic system, due to the difference in the measurement of turbidity of the different influents and effluents according to time.

The filtration system

The coupling of the granular activated carbon filter and the cellulose fiber filter contributed to the elimination of the color of the treated wastewater, which is expressed in nephelometric units of turbidity (NTU), is a unit used to measure turbidity, as can be seen in Table 2.

Sample number/No. of Month	Influencers (UNT)	Effluents (UNT)
1	250	130
2	240	139
3	230	136
4	270	129
5	245	125
6	220	115
Average	243	129

Table 2 Results of the measurement of turbidity of the influents and effluents in different months with influents of 1 and 2 L

Physicochemical analysis of the 3 flows and obtaining the percentages of reduction.

During the treatment of the 3 different effluents (3, 5 and 7 Liters), the pH and temperature conditions of the sludge were as follows: pH of 7.2 – 8.0 and temperature range of 11 – 28 °C. These conditions are within an acceptable range for treatment in anaerobic systems, so it was not necessary to add reagent to neutralize the pH or heat to increase the temperature. It should be noted that the optimal conditions in this treatment are: temperature > 35 ° C and pH between 7-7.5, but it could be shown that an efficient reduction of contaminants was possible, even without operating at the optimal conditions for these systems. Table 3 shows the averages of the results of the analysis of effluents of 3, 5 and 7 liters and compares them with the values specified with NOM-003-SEMARNAT-1997. Table 3 shows that for effluents of 3 and 5 Liters the standard was met and for the effluent of 7 Liters, only the BOD_5 was not complied with.

The percentages of reduction of the pollutants indicated in the same regulations of the 3 effluents are indicated in table 4.

	Fecal Coliforms NMP/ 100 mL	H H (h/L)	Fats and oils mg/L	BOD_5 mg/L	SST mg/L
Values of NOM-003-SEMARNAT-1997	1,000	1	15	30	30
Vol. de 3 L	3	< 1	3.0	27	29
Vol. de 5 L	25	<1	3.6	19	30
Vol. de 7 L	435	<1	1.2	55	26

Table 3 Comparison of the parameters obtained from the effluents with the values indicated in the nom-003-SEMARNAT-1997 regulation

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This was achieved by further stabilizing the system. Finally, it was observed that by increasing the flow and therefore the organic load of 3-5 Liters, an increase in the reduction of these contaminants was obtained, due to the increase in the stability of the system. On the contrary, by increasing the flow to 7 Liters, although for BOD_5, COD, and fecal coliforms the reduction did not increase with respect to the effluent of 5 Liters, still a similar reduction difference was obtained between these two effluents of 5 and 7 Liters (Table 4).

Sample	BOD_5 % of decrease	DQO % of decrease	SST % of decrease	Fecal Coliforms % of decrease	H H % of decrease	Fats and oils % of decrease
3 L	90	66	90	99.9	100	9
5 L	93	71	90	99.9	100	0
7 L	80	65	91	99.9	100	64

Table 4 Percentage of removal of organic and microbial load in the treated wastewater (effluent) compared to the influent

Analysis of the fixation of the biofilm to the PET by Scanning Electron Microscopy

The fixation of the anaerobic sludge biofilm to the PET columns after 6 months was carried out as shown in Figure 5.

Figure 5 Adhesion of the biofilm in an anaerobic system after 6 months

The pH and temperature conditions during the biofilm fixation stage were: pH 7.2 – 8 and temperature range 12 – 27 °C. The analyses of the biofilm by Scanning Electron Microscopy are shown as shown in Figure 6, which served as a verification of the adhesion of this, in order to confirm that the anaerobic microorganisms adhere to the PET and therefore improve the treatment by being in a greater area of contact.

It is claimed that the biofilm is mostly made up of bacteria, by the size ranging from 0.5-5 μm and the shapes of these. Therefore, this set of microorganisms-biofilm, interact to be fixed to the PET, improving the treatment.

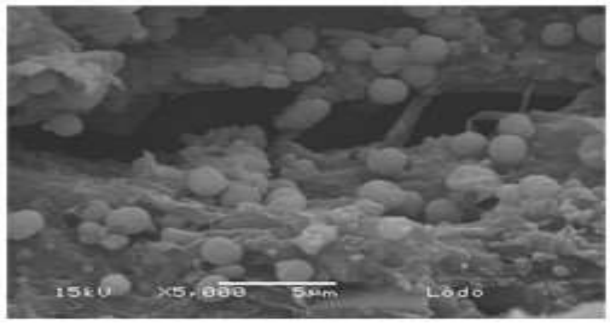

Figure 6 Analysis by Scanning Electron Microscopy (15 kV, X 5,000 and 5μm)

Gratitude

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Conclusions

The fixation of the biofilm to the PET after 6 months was achieved, which is a suitable material for its fixation, to the conditions under which the system was operated (temperature, pH and volume of wastewater) and percentages of removal of the evaluated parameters similar to those obtained in anaerobic systems in general (UASB and among other anaerobic systems) and with aerobic systems were obtained.

The fixation of the biofilm by scanning electron microscopy.

The stabilization of the system was achieved after 3-6 months of adaptation of the inoculum to the influent, with the pH and temperature conditions obtained.

Granular activated carbon was chosen as the filter medium of the effluent according to the results obtained from turbidity and COD in the filtered with granular activated carbon and zeolite.

The percentage of removal increased for the parameters of BOD_5, COD, SST, fecal coliforms and fats and oils, in the effluents of 3 and 5 Liters, this due to the increase in the stability of the system, as well as the increase in the organic load. With respect to the effluent of 7 Liters there was no significant increase in the decrease of these parameters, but the percentages of decrease were similar to these effluents.

The UASB type system using, brings economic benefits by not using reagents or energy compared to other systems of the same type obtaining important percentages of removal compared to biological systems. The environmental regulations NOM-SEMARNAT-1997 were complied with for effluents of 3 and 5 Liters, with the exception of the effluent of 7 Liters, where only the boD5 parameter did not meet.

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