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СРАВНИТЕЛЬНОЕ ИССЛЕДОВАНИЕ РЕАКТОРА С ВОСХОДЯЩИМ ПОТОКОМ ЧЕРЕЗ СЛОЙ АНАЭРОБНОГО ИЛА (UASB РЕАКТОР) И БИОПЛЕНОЧНОГО РЕАКТОРА, СОДЕРЖАЩЕГО *OPUNTIA IMBRICATA* В КАЧЕСТВЕ НОСИТЕЛЯ, ПРИ ОБРАБОТКЕ СТОЧНЫХ ВОД ТЕКСТИЛЬНОЙ ПРОМЫШЛЕННОСТИ

И. Родригес-Гарса, И. Гарса-Гарсиа, Х. Родригес-Мартинес*

*(Отделение биотехнологии химического факультета Автономного университета штата Коауила, Мексика. U.A. de C. Blvd. V. Carranza e Ing. José Cárdenas V., C.P. 25000. Saltillo, Coah.Тел. (844) 415-57-52, 415-53-92, 415-70-15, доб. 22. Факс (844) 415-95-34. *E-mail: jrodrigu@mail.uadec.mx)*

Проведены оценка и сравнение кинетики и эффективности работы реактора с восходящим потоком через слой анаэробного ила (UASB-реактора) и биопленочного колоночного реактора, заполненного природным носителем *Opuntia imbricata*. Работу обоих реакторов сравнивали при различных временах гидравлического задержания (ВГЗ). Показано, что наибольшей эффективности обработки можно достичь при ВГЗ 30 ч. В этом случае удаление ХПК составляет 73% в UASB-реакторе и 90% в биопленочном реакторе. Анаэробные биопленочные реакторы, заполненные O*puntia imbricata*, повышают эффективность обработки сточных вод и могут успешно заменить традиционные реакторы, применяемые при очистке сточных вод текстильной промышленности.

Introduction

Wastewater recovery and reuse is particularly significant for the textile industry, which is generally characterized with high water consumption. At present, textile effluents are subjected to stringent limitations for discharge into receiving waters and often require full biological treatment for compliance [6]. In addition, the discharge of textile industry wastewater is undesirable not only for aesthetic reasons but also because it contains many azo dyes. These azo dyes and their breakdown products are toxic to aquatic life [3] and mutagenic to humans [4].

Worldwide, some 280,000 tons of textile dye are discharged per annum. Degradation of the predominant highly soluble reactive dyes is poor in activated sludge plants and they require anaerobic pretreatment for reductive cleavage of the chromogenic azo- bonds to precede the usual aerobic degradation [12].

In our research, we proposed a new strategy to increase the efficiency and economy of the treatment process by introducing new support materials. For the past four years, the Department of Biotechnology of the Autonomous University of Coahuila, Saltillo has been working on the development of both aerobic and anaerobic biofilm reactors with a natural support, *O. imbricata* for the treatment of different wastewaters [10].

A biofilm is a complex structure of cellular aggregates mediated by chemical intercellular molecules for their adherence to a support material which can be natural or synthetic [2, 7]. These systems are known as fixed film systems and are very much different from the suspended sludge systems. This implied that the electron donor, electron acceptor and all the other nutrients are to be transported to the microorganisms on the biofilm by diffusion or another transport process. The biofilm nature and behavior is dependent on the nature of support used for the biofilm formation [5].

Generally, support for biofilm systems are selected based on their mechanical stability and biomass retention [11]. However it is essential to select supports with high surface activity, resistance to the shock loads, buffering capacity and finally their cost. They should be more economic so that they can be used widely in developing countries. The knowledge on the operation of bioreactors has lead to short hydraulic retention time, high efficient removal of organic matter, low sludge production and less space requirement [11]. *O. imbricata* exhibits such a potential and can be used in the development of low cost treatment technology, which also will support the livelihood of the people in rural Mexico, as this shrub is widely distributed in North Mexico.

Hence, it is proposed to study and compare the efficiency of anaerobic biofilm reactors packed with *O. imbricata* with an UASB reactor in the treatment of textile industry wastewater.

Methods

Wastewater and Inoculum

The wastewater used in the study was collected from a textile industry in Parras, Coahuila state, Mexico. The COD concentration of the wastewater was in the range of 3–5 g/l and the characteristics of this wastewater are summarized in Table 1. The inoculum used in this study was granular sludge from an Upflow Anaerobic Sludge Blanket (UASB) reactor treating textile industry wastewater. The pH and volatile suspended solids (VSS) of the inoculum was 8.3 and 21.4±1 $g.l^{-1}$ respectively.

Two UASB reactors (3.2 l; 60×7.5 cm), with 10 sampling ports located in differents places of the column were used in this study. The UASB reactor was inoculated with 1.5 l of granular sludge. The anaerobic biofilm reactor was packed with *O. imbricata* (9×2.5 cm; Fig. 1) up to the height of effluent exit port (Fig. 2) and inoculated with 1l of granular sludge for biofilm formation. Wastewater was fed at different rates to achieve a HRT of 13, 24, 30, and 42 hours using peristaltic pump. The pH of the wastewater was initially 11 and was adjusted to 7.5 using 1 N H_2SO_4 before fed to the reactor. Volatile Fatty Acids (VFA) and methane were measured by gas chromatograph (GC)

Table 1

Characteristics of the textile wastewater used in this study

Parameters	Units
Colour (Pl–Co units)	1600
pH	10–11
Electrical conductivity (μmhos.cm^{-1})	3771
Biochemical Oxygen Demand ($mg.l^{-1}$)	900
Chemical Oxygen Demand ($mg.l^{-1}$)	3057.6–5000
Total suspended solids ($mg.l^{-1}$)	480
Total Nitrogen ($mg.l^{-1}$)	94.2
Total Phosphorus ($mg.l^{-1}$)	4.7
Oils and grease ($mg.l^{-1}$)	16.1

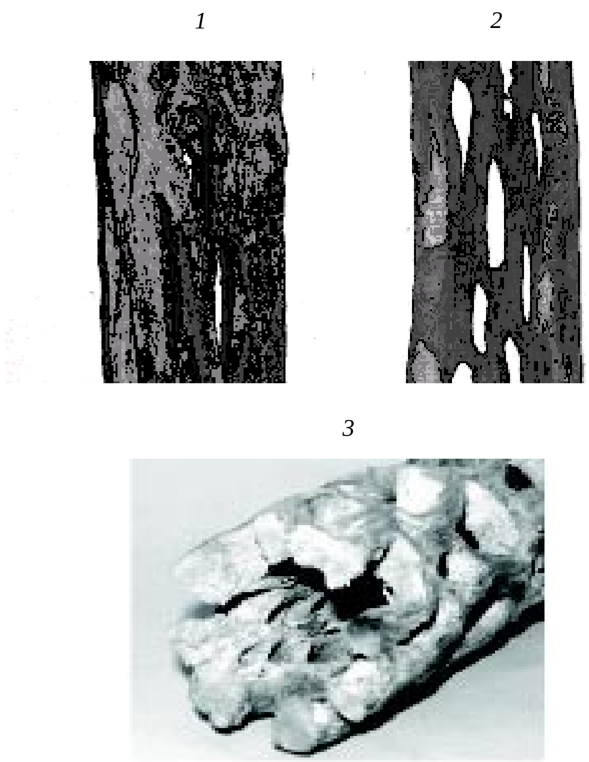

Fig. 1. Natural Support, *Opuntia imbricata*, (*1*) complete cylinder, (*2*) transversal cut, (*3*) top view

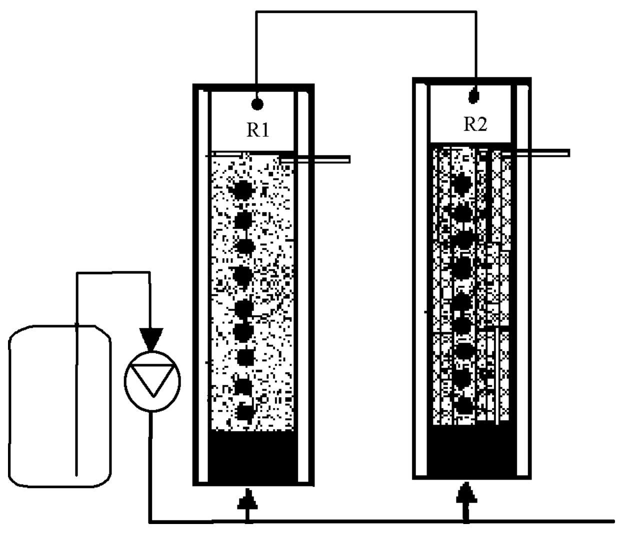

Fig. 2. Biofilm reactor with NS *Opuntia imbricata* (R1), UASB reactor (R2)

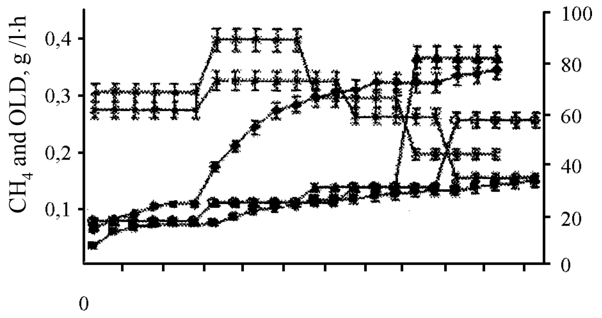

Fig. 3. Organic loading rate, methane formation and removal efficiency at all HRT

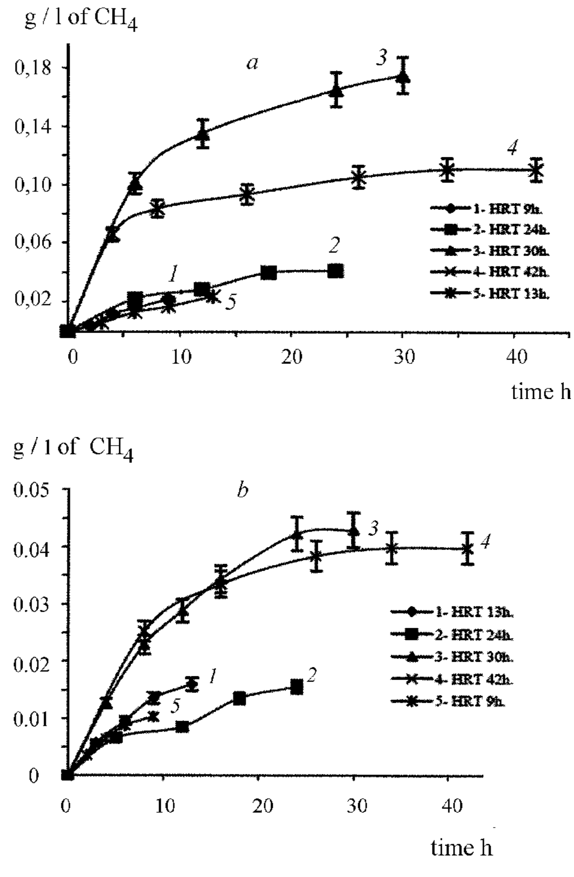

Fig. 4. Influence of HRT on CH_4 formation in: *a* – biofilm reactor with NS; *b* – UASB-reactor

Varian gas chromatograph equipped with a flame ionization detector (FID) and thermal conductivity detector (TCD) respectively. Chemical Oxygen Demand (COD) was measured as per standard methods [1]. During the experiment, VFA production was measured in all sample ports.

Results and discussion

Methane formation with respect to organic loading rate and COD removal at all HRT for both reactors is presented in Fig. 3. At 114 hours of continuous operation under different HRT, the anaerobic biofilm column reactor packed with NS accumulated methane up to 0.35 g/l. At the same time, the UASB reactor produced only 0.15 g/l, which meant that there was 2.3 times of more methane production in biofilm reactor.

The methane formation in biofilm and UASB reactors with relation to the different HRT are given in Fig. 4, *a* and Fig. 4, *b* respectively. The initial velocity of CH_4 formation is presented in Table 2. At all HRT methane formation was significantly more in biofilm reactor than UASB reactors, in spite of the fact that biofilm reactors contained less biomass than UASB reactor (Table 2). In both reactors, there was no linear relation between methane formation and HRT (Fig 5). Methane

Table 2

Velocity formation of CH_4 at different HRT in both rectors

HRT (hours)	Velocity of methane formation (V_0 g/l×h^{-3})	
	UASB reactor	Biofilm reactor with NS
9	0.961	2.7
13	1.2	3.2
24	1.3	5.4
30	2.9	16.8
42	2.1	5.3

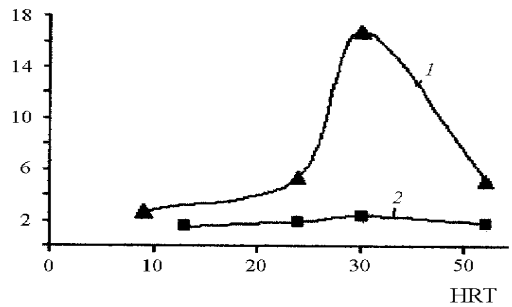

Fig. 5. Initial velocity of CH_4 formation as a function of HRT

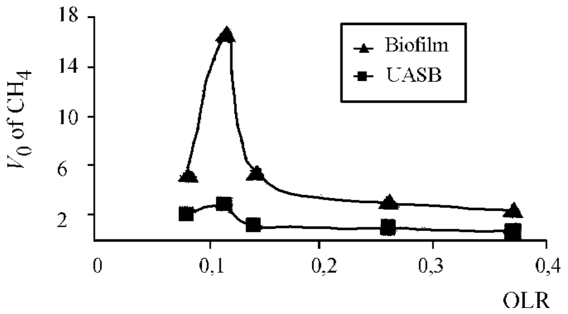

Fig. 6. Velocity of methane formation in relation to OLR

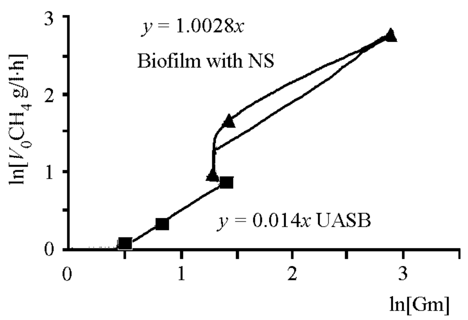

Fig. 7. Kinetic of methane formation as a function of Ln V_0 = Ln K + nLn[Gm]; where V_0 is initial velocity of methane and Gm is accumulated methane

formation was dependent on COD concentration and the velocity of methane formation was a function of OLR.

Both reactors showed similar optimum OLR, but the velocity of methane formation was nearly 5 times higher in biofilm reactor than UASB reactor (Fig. 6, Table 2). The biofilm reactor maintained a pH around 7.5 during and as well as at the end of study period, where as it was 8 and slightly above pH 8 in UASB reactors (Table 3). The support in the biofilm reactor aided in maintaining the pH at near neutral range and this buffering capacity allowed higher COD removal and higher methane production in biofilm reactor.

The kinetics of the present study was analyzed by following equation developed by Fiestas et al. [5]:

$$G = G_m\ [1 - e^{-\mathrm{kat}}]. \quad (1)$$

Where G_m is the maximum volume of methane accumulated at an infinite digestion time and is the product of the initial substrate concentration (S_0) and the yield coefficient of the product (Y_p): $G_m = S_0Y_p$; and k_a is apparent kinetic constant that includes the biomass concentration (x): $k_a = kx$.

Eq. (1) was in agreement with the finding empirically established by Edeline [4]) and Rodriguez-Martinez [9]. Almost constant biomass concentration (x) in the digesters assisted in comparison and interpretation of the results. The same parameters as indicated in eq. (1) was used for methane formation and it was observed that the reaction was of first order kinetic model for both cases. The kinetic constant in biofilm reactor with NS was higher (1.42 h^{-1}) than the UASB ($0.96 \cdot 10^{-2}$ h^{-1}) (Fig. 7). The kinetic constant for column reactor was 50 times more than that was reported by Wuhrmann et al. [14], Carliell et al. [15] and van der Zee et al. [13], which was 1.0 and $2.5 \cdot 10^{-2} h^{-1}$ for blue and black dyes respectively.

It was observed that the presence of NS in biofilm reactor influenced the biodegradation efficiency of the process. It was also observed that the support favored a significantly higher methanogenic activity in biofilm reactors than the UASB reactor (Table 4).

Conclusions

The optimum HRT for both reactors was 30 hours, but biofilm reactor showed more RE, and methane production than UASB reactor. The support provided buffering capacity to the changes in pH and allowed high operational stability. Results obtained and kinetic analyses clearly demonstrated a new generation of biofilm reactors with higher efficiency and operational stability for treatment of textile wastewater can be developed with the natural support used in this study.

Table 3

Profile of pH at the end of the study period with different HRT

HRT (hours)	pH*	
	Biofilm reactor	UASB reactor
9	7.12	7.8
13	7.3	7.8
24	7.5	8.1
30	7.7	8.5
42	7.98	8.7

* Initial pH was 7.5.

Table 4

Methanogenic activity in biofilm and UASB reactor fed with textile industry wastewater

Reactor	Accumulated methane (G_m)	OLR g/l·h	V_0 CH_4	Methanogenic activity CH_4 (g·l^{-1}·g^{-1} of VSS) ·10^{-3}
	g/l·10^{-2}		g/l·h·10^{-3}	
UASB	4.29	0.1128	1.8	1.63
Biofilm with NS	17.5	0.1128	16.8	28.1

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COMPARATIVE PERFORMANCE OF AN UASB AND A BIOFILM REACTOR WITH OPUNTIA IMBRICATA AS A SUPPORT IN THE TREATMENT OF TEXTILE INDUSTRY WASTEWATER

I. Rodriguez-Garza, Y. Garza-Garcia, J. Rodriguez-Martinez*

*(Dpto. de Biotecnología, Facultad de Ciencias Químicas, U.A. de C. Blvd. V. Carranza e Ing. José Cárdenas V., C.P. 25000. Saltillo, Coah. Tel. (844) 415-57-52, 415-53-92, 415-70-15, ext. 22 . Fax. (844) 415-95-34. *E-mail: jrodrigu@mail.uadec.mx)*

Search for new strategies to increase the efficiency and economy of the treatment process has lead to the introduction of new materials. Department of Biotechnology of Autonomous University of Coahuila, Saltillo has been working with *Opuntia imbricata* as a natural support for t-he development of aerobic and anaerobic biofilm reactors to be used in the treatment of various kinds of wastewater for the last four years. The objective of the present study was to evaluate and to compare the kinetics and removal efficiency (RE) of an UASB reactor with a biofilm column reactor packed with natural support, *O. imbricata* (NS). The performance of both reactors was evaluated at different HRT and it was observed that a HRT of 30 h recorded maximum treatment efficiency. At this HRT, COD removal in the UASB reactor was 73%, where as it was 90% in biofilm reactor. Our results demonstrated that anaerobic biofilm reactors packed with *Opuntia imbricata* improved the efficiency of treatment and can be a better alternative to traditional reactors in the treatment of textile industry wastewater.