International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Organic Matter Removal in a Lab-Scale Activated Sludge Reactor, Using Textile Wastewater and Nanofiber Carriers

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Abstract— *The use of new technologies such as the production of nanomaterials to create moving bed biofilm reactors (MBBR) have the potential to increase the colonization area and the efficiency of the pollutant treatment process; activated sludge is one such process widely used in Mexico and around the world but which can hinder treatment, particularly in industrial wastewater. The aim of this study was to determine the efficiency of organic matter removed in a pilot activated sludge reactor first with textile wastewater and subsequently increasing the biomass carriers in the system. An aerobic reactor with aeration control and a timer were used to adjust cycles and input volume with a working capacity of 3 L (bioreactor). The reactor was fed first with domestic wastewater and then with wastewater from a textile mill. Samples were taken of the influent and effluent. Slightly more organic matter was removed with the carriers. The effluent water with the carriers more closely met the Mexican Standard. The main problem with the results obtained may be due to insufficient aeration to maintain the distribution of the carriers throughout the reactor. Despite this, in general the system achieved its primary objective which is the removal of organic matter.*

Keywords— *BOD_5 removal, fecal coliform removal, MBBR, Textile industry.*

I. Introduction

Good water quality—determined by its intended use—is essential for preserving human health. According to figures from the World Health Organization (WHO) in 2017, three out of ten persons worldwide suffer from a shortage of drinking water. The scarcity is due to the population growth and the climate change, which have tripled the extraction, pushing the population to use treated industrial wastewater and to the need of aquifers recharging [1].

Furthermore, industrial wastewater requires in many cases advanced treatment processes to decrease pollutant concentrations, which otherwise will affect water quality and, therefore, aquatic and human life. Among the polluting industries in Mexico, the textile industry is one of the most important for the economy contributing 0.7% of GNP [2], but which consumes huge amounts of water generating large quantities of water pollutants due to the use of toxic and non-biodegradable materials and the production of synthetic chemical fibers [3].

To remove some of these pollutants, some biological processes might be applicable; in Mexico the most common are still biological filters, stabilization ponds and mainly activated sludge [4].

The activated sludge system, one of the most widely used, is a biological treatment comprising a mass of microorganisms in aeration, mainly heterotrophic bacteria and protozoan communities. These microorganisms first digest part of the organic matter generating waste, which afterwards will be the feed for other organisms, until the entire biodegradable matter had been removed. Protozoa feed mainly of free-swimming bacteria and help to reduce the suspended solids in the water; conglomerates of organisms or flocs promote sedimentation. Once settled, the sludge is recirculated and excess of solids are discarded [5, 6, 7]. This system not only reduces organic matter (biochemical oxygen demand, BOD_5, chemical oxygen demand, COD) but also reduces nutrients such as nitrates, nitrites and ammonia.

Nevertheless, the efficiency of this bio-system is affected by many industrial discharges due to the high toxicity of their components, as in the case of textile mills, directly affecting the population of pollutant-degrading microorganisms, and as a result the removal efficiency [8].

The use of new technologies such as the production of nanomaterials for the creation of moving bed biofilm reactors (MBBR) has the potential to increase the colonization area and the efficiency of the pollutant treatment process, so that the biofilm formed in the carrier can protect the biomass from process fluctuations, and generate a more specialized bacterial consortium that improves the efficiency of the conventional bioprocesses, like those still widely used in Mexico and many parts of the world. This technology is based on the growth of biomass (in the form of biofilm), on a supporting or carrying material, which is in continuous movement in the biological reactor. These carriers are small in size and must have, preferably, a high specific surface area per unit volume, enabling the growth of more biomass to be comparable with the biological flocs of conventional reactors [9, 10, 11].

In the literature, several authors have used this type of technology, as in the case of Saidi *et al.*, 2017 [12], who treated high load greywater with a multi-stage moving bed biofilm reactor (MBBR), finding the highest reduction rate in the third reactor in terms of DOC (dissolved organic carbon) and BOD; Ashkanani *et al.*, 2019 [13], evaluated the impact of the characteristics of biocarriers in the elimination of ammonia

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by MBBR concluding that MBBR technology is a feasible option for the treatment of real wastewater effluent containing high concentrations of ammonia; di Biase, *et al*. 2019 [14], reviewed the development of the municipal wastewater treatment process using MBBR from the initial stages to recent advances; Liu *et al*., 2019 [15], evaluated the performance of a laboratory scale MBBR that uses polyethylene as support material in the treatment of wastewater polluted with terephthalic acid (TPA), achieving after 15 days from start-up an operating period of 65 days maintaining stable TPA removal efficiencies and COD of 68% and 76%, respectively. Thus, various authors have worked with moving carriers seeking better removal in different types of wastewater, such as concentrated reverse osmosis (Wang *et al*., 2020) [16]; aquaculture wastewater (Li *et al*., 2019) [17]; textile wastewater (Yang *et al*., 2020) [18], pharmaceutical wastewater El-taliawy *et al*., (2018) [19]; in oil refinery effluents (Nava *et al*., 2014) [20]; or varying the type of material or carrier concentration (Zhao *et al*., 2019; [21] or simply looking for different ways of removing a certain parameter from domestic wastewater (Mohammadi, *et al*., 2020) [22].

Due to the importance given by various authors to the use of nanofibers in biological reactors such as activated sludge, the aim of this study was to determine the efficiency of organic matter removed in a lab-scale activated sludge reactor first with textile wastewater and subsequently introducing biomass carriers into the treatment vessel.

II. Methodology

In the first period, an aerobic reactor with aeration control and a timer were used to adjust cycles and inlet volume with a working capacity of 3 L (bioreactor). The reactor was fed with wastewater from a textile mill, after adapting the biomass from domestic sludge.

In the second period, polymeric nanofiber carriers were introduced into the same reactor.

In both periods, samples of the influent and effluent from the reactor were taken at different operational days. The bacteriological samples were taken in sterile 500 ml flasks, and total coliforms and fecal coliforms were determined, using the Most Probable Number technique (MPN) [23].

The samples for the physicochemical parameters were taken in a 1.5 L bottle to determine biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen and suspended solids [23]. With the obtained results, the removal percentage of each parameter was calculated; the averages of the results of the effluent were compared with the maximum permissible limits of the Official Mexican Standard [24].

III. Results and Discussion

a) First period

Following the conditioning time of the bioreactor—when domestic activated sludge was gradually replaced with sludge from a textile mill until feeding was 100% textile wastewater—the period was continued with sampling at input and output of the bioreactor initially on a weekly basis and subsequently two-weekly and some monthly samples starting from 2017 and ending in September 2018. The control parameter was mainly COD due to its short analysis time, followed by BOD_5, occasionally checking ammonia and suspended solids (Table 1).

TABLE 1. Average results of the physicochemical and bacteriological parameters of the influent and effluent water samples of the bioreactor.

Parameter	Bioreactor	
	Influent Average	Effluent Average
Fecal coliforms, (MPN/100 ml)	Geometric mean: 1,069,696	14.0
Biochemical Oxygen Demand, (BOD_5) (mg/L)	130	25.1
Chemical Oxygen Demand, (COD) (mg/L)	553	297
Ammoniacal nitrogen, (mg/L $N\text{-}NH_4$)	27.72	3.69
Suspended solids, (mg/L)	22.5	14

Removal percentages were calculated from the result averages (Table 2).

The parameters that presented better removal were fecal coliforms, ammoniacal nitrogen and organic matter through BOD_5

Based on the literature [25], coliform removal in these systems is low (average 50%), being higher in the shown results. Meanwhile, the highest removal was of organic matter, which agrees with the literature [26]; the removal of ammoniacal nitrogen also coincided with the decrease in BOD_5, indicating that the system is working properly. In this first period only 37.77% of solids were removed.

Comparing average effluent parameters with NOM-003-ECOL-1997 (Table 3), the values of fecal coliforms and suspended solids are within the maximum permissible limit of treated water reused for service to the public with both direct and indirect contact, but BOD_5 only meets the standard for indirect contact.

TABLE 2. Removal percentages of the analyzed parameters

Parameter	Average removal percentages
Fecal coliforms, (MPN/100 ml)	73.73
Biochemical Oxygen Demand, (BOD_5) (mg/L)	80.66
Chemical Oxygen Demand, (COD) (mg/L)	46.25
Ammoniacal nitrogen, (mg/L $N\text{-}NH_4$)	86.7
Suspended solids (mg/L)	37.77

TABLE 3. Comparison of average effluent results against the Mexican standard NOM-003-ECOL-1997

Parameter	Service to the public with direct contact	Service to the public with indirect or occasional contact	Average
Fecal coliforms, (MPN/100 ml)	240	1000	14
BOD_5, (mg/L)	20	30	25.1
Suspended solids, (mg/L)	20	30	14

b) Second period

The second period began when nanofiber carriers were introduced in September 2018 through June 2019, with samples taken in the same way as the first period (Table 4).

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The average results were used to calculate the removal percentages (Table 5).

The highest removal in this second period (MBBR) was BOD_5, slightly lower than reported in the literature. [26].The COD and ammoniacal nitrogen were much lower than expected. Coliform removal was also lower than the expected average (50%). The removal of solids was greater than 50%.

The comparison of average effluent values with NOM-003-ECOL-1997 shows that BOD_5 and suspended solids are within the limits of the standard for direct contact use but fecal coliforms exceed the limit (Table 6).

c) Comparison between the two periods

The removal of ammoniacal nitrogen was better in the first period, without carriers. This may be due to the fact that in the second period there had been a very high increase in ammoniacal nitrogen in the influent coming from the possible discoloration with ammonium hydroxide of a poorly worked batch of clothing, which in combination with the poor efficiency of the bioreactor with the carriers resulted in an elevated concentration of ammoniacal nitrogen in the effluent (Figure 1). This does not match the findings of authors such as Ashkanani *et al*, [13], who consider that the biomass carrier system is good for removing nitrogen and could be more useful in effluents with high concentrations of ammoniacal nitrogen. However, when Wang et al tested carriers of 4 different diameters and lengths, they found that 15 x 15 mm gave the best ammoniacal nitrogen removal at 55.56%, slightly higher than obtained in this study (41.25%).

Effluent suspended solids decreased when carriers were added.

TABLE 4. Average results of the physicochemical and bacteriological parameters of the influent and effluent water sample of the moving bed biofilm reactor (MBBR).

Parameter	Moving bed biofilm reactor	
	Influent Average	Effluent Average
Fecal coliforms, (MPN/100 ml)	Geometric mean: 153,267	Geometric mean: 3228
Biochemical Oxygen Demand, (BOD_5) (mg/L)	61.71	10.12
Chemical Oxygen Demand, (COD) (mg/L)	335	157
Ammoniacal nitrogen, (mg/L N-NH_4)	9.36	5.5
Suspended solids, (mg/L)	6.68	2.43

TABLE 5. Removal percentages of the analyzed parameters of the moving bed biofilm reactor, (MBBR).

Parameter	Average removal percentages
Fecal coliforms, (MPN/100 ml)	32.33
Biochemical Oxygen Demand, (BOD_5) (mg/L)	83.59
Chemical Oxygen Demand, (COD) (mg/L)	53.19
Ammoniacal nitrogen, (mg/L N-NH_4)	41.25
Suspended solids, (mg/L)	63.67

The carrier system showed only a slight increase in BOD_5 removal at 83.59% compared to the result without carriers of 80.66%; COD removal with carriers was 53.19% and without carriers 46.25% (Figure 1). This is in disagreement with Liu et al. and Nava et al. who obtained removal percentages greater than 70% [15, 20].

TABLE 6. Comparison of average effluent results against the Mexican standar NOM-003-ECOL-1997

Parameter	Service to the public with direct contact	Service to the public with indirect or occasional contact	Average
Fecal coliforms (MPN/100 ml)	240	1000	3228
BOD_5 (mg/L)	20	30	10.12
Suspended solids (mg/L)	20	30	2.43

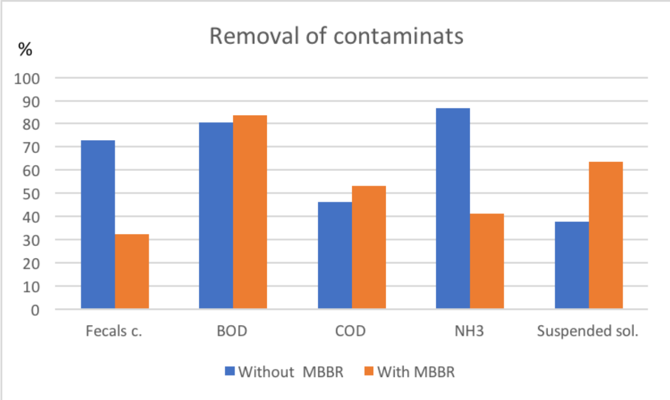

Figure 1. Comparison of the average removal values of the analyzed parameters before and after putting the MBBR in the bioreactor

In the literature, the biomass carrier reactor system improves the removal efficiency of BOD_5 and COD by increasing the contact area of the microorganisms thus increasing their capacity to degrade organic matter. However, the removal of pollutants from industrial wastewater can be similar in both reactors, as in the case of Nava *et al.*, [21] who in 2014 compared the two systems using wastewater from a refinery finding phenol removal of more than 98% in both reactors indicating that the biomass of both reactors was able to degrade the toxic compounds present.

Both fecal coliforms and chemical oxygen demand (COD) had lower removal percentages with carriers, of 32.33% and 53.19%, respectively. However, the COD values were slightly higher than those obtained without carriers.

The efficiency of the biomass carrier reactor system relies on the action of the microorganisms that become attached and form a biofilm, along with a continuous aeration source which not only provides the necessary oxygen for the degradation of the organic matter but also allows the carriers to be in constant motion within the reactor. One of the issues in this work was that the movement of the carriers was limited to the surface of the reactor, which might change the reactor's performance regarding the complete diffusion of the nutrients into the carrier biofilm.

Wastewater from the textile industry contains large concentrations of dyes, and other organic pollutants and toxic compounds, which can lead to microorganisms inhibition as in the biofilm that forms in the carriers, as in the suspended biomass. So only the properly acclimated biomass may play a role in the degradation efficiency of such compounds, and a specific removal capability depends also on other factors like feeding cycle period and the differences of the subsequent batches of wastewater, given the fact that this work is treating real textile wastewater batches. The low fecal coliform removal in the carrier system might be due to the fact that these organisms are not purged by a sludge recycling protocol, but many might remain in the vessel for longer periods than when they are associated to the suspended solids.

Based on the Mexican regulation, during the period without carriers, effluent BOD_5 would indicate that the outlet only be suitable for indirect contact use, while the effluent quality for the period with carriers the water would be suitable for all uses once disinfected, since coliforms exceeded the standard for both uses [24].

IV. Conclusions

The system with carriers showed a slight increase in the removal of organic matter compared to the system without carriers.

The organic matter removal efficiency was good although it could have been better.

The carrier system had the best results for reusing effluent water, although a disinfection process must be taken into account before use.

Efficient aeration and the carrier material are essential factors to ensure better removals, however the carriers showed to be good enough to compete with conventional activated sludge.

It should be mentioned that this was one of the first works reported in the literature in Mexico where biomass carrier reactor systems are used and subsequent studies performed to determine whether removal can be improved by varying the composition and size of the carriers or modifying any of the steps in the methodology presented herein.

Aknowledgements

The authors want to thank finance support from Project FESI-DIP-PAPCA-2016-1 from UNAM, FES Iztacala.

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