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CODs Removal of Domestic Wastewater by Solid Plastic Wastes Materials: Influence of Organic Loading Rate

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Abstract

Polyethylene terephthalate from beverage bottles, and polypropylene from plastic of sacks, collected from recycling plants were tested as biofilm support in aerobic submerged fixed biofilm reactors, fed with real domestic wastewater. Soluble chemical oxygen demand (CODs) and volatile suspended solids (VSS) were constantly monitored while organic loading rate (OLR) was varied between 0.30 to 5.00 g CODs m^{-2} d^{-1}. CODs removal efficiencies were up to 90% for OLR under 1.00 g CODs $m^{-2}d^{-1}$ and 80% for OLRs between 1.0 to 2.50 g CODs $m^{-2}d^{-1}$, also efficiencies down to 70% were achieved for OLR between 4 to 5 g CODs $m^{-2}d^{-1}$. Total attached biomass was 1.35 g VSS m^{-2} for PP and 1.023 g VSS m^{-2} for PET. In a practical approach, the recycled materials PET and PP could be used as support materials in AFBR for urban wastewater treatment.

Keywords: Biofilm, wastewater treatment, aerobic, recycled materials, PET, PP.

Research relevant points

- Two recyclable solid plastic wastes (PET and PP) were assessed as support material in aerobic fixed biofilm reactors (AFBR), being recommendable organic loadings lower than 2.5 g COD m^{-2} d^{-1}
- The COD removal efficiency depend on the surface organic loading (OLR).

1. INTRODUCTION

The lack of wastewater treatment systems remains without an efficient solution, mainly in developing countries, where the weak institutional management and insufficient politics do not promote an integrated use of water (Ujang and Buckley, 2002). Particularly small populations has to face with many factors such as limited economies, variability in the wastewater characteristics and the lack of technical and human resources, which do not let the application the large scale systems (Aragón et al., 2011). In this context, the searching for low-cost as well as practical technologies plays a fundamental roll in order to manage the treatment of sewages.

Regarding to wastewater treatment technologies, biofilm based is one of the technologies which has a great application potential; this technology uses support materials to attach biological films. The use of adhered biomass, instead of suspended biomass allows the construction of smaller reactors and facilitates the separation of biosolids from the treated water (Bassin et al., 2016). Others advantages of the biofilm processes over the traditional methods include a better oxygen transference, shorter hydraulic retention times, higher rates of organic load removal, higher rates of nitrification and higher specific area available for mass transference (Chan et al., 2009; Sombatsompop et al., 2006). To ensure the effectiveness of biofilm systems, it is mandatory the use of support materials that could provide stable attachment and growth of high amounts of biomass. In this context, business companies are dedicated to manufacture and sell support materials based on plastics, i.e. Headworks BIO, Veolia Inc., AqWise, Siemens Water Technologies Corp., etc, which mainly are applied on mobile bed reactors. However, the use of these materials supposes its acquisition and consequently an increase in the cost of the system.

On the other hand, plastic solid wastes (PSW) call the worldwide environmental attention, 150 million tons per year are globally produced; industries are increasing the manufacturing of plastics, thus the recycling/recovery/management of PSW is a matter of concern (Singh et al., 2017). In Latin America the proportion of plastics in general solid wastes, oscillates between 9% and 14% (Vázquez Morillas et al., 2016). Polyethylene terephthalate (PET) and polypropylene (PP), are important part of the residues. PET come from beverage bottles and PP are mainly sacks

In primary insight these PET and PP plastics have the required characteristics for being used as biofilm growth material. Thus, the possibility of using these materials is feasible, provided that they could form and retain active biomass inside the reactor and being operated in appropriated conditions. Several support materials have been evaluated, for example, (Saucedo-Terán et al., 2008) tested ten support materials in fluidized bed reactors, where was found that the mixture of expanded polyester-perlite and vitrified perlite was the best material, additionally Cervera Bonilla and Tavera Tavera, (2006) evaluated low density recyclable materials like granulated PET, polyurethane foam and polystyrene.

The use of biofilm reactor in limited economies is extended to the use of rocks, clays and other hard materials that do not possess favorable conditions for a good treatment performance. Nevertheless, the use of the recycled PSW in this raw form has not been tested. In this context, the present research aims the technical feasibility study of the application of both plastic materials PET and PP as support material in AFBR, focused on a practical perspective

2. MATERIALS AND METHODS

2.1 Support materials

Polyethylene Terephthalate (PET) and polypropylene (PP) were obtained from a recycling plant located in Machala-Ecuador. The pre-treatment of PET consisted in washing the material with abundant water and cut in segments of 5 cm large by 2 cm wide. Besides, PP were cut in strips of approximately 80 cm large by 5cm wide prior washing with water. Both materials were arranged in the reactors according to Figure 1. The materials occupied the 50% of the total reactor volume.

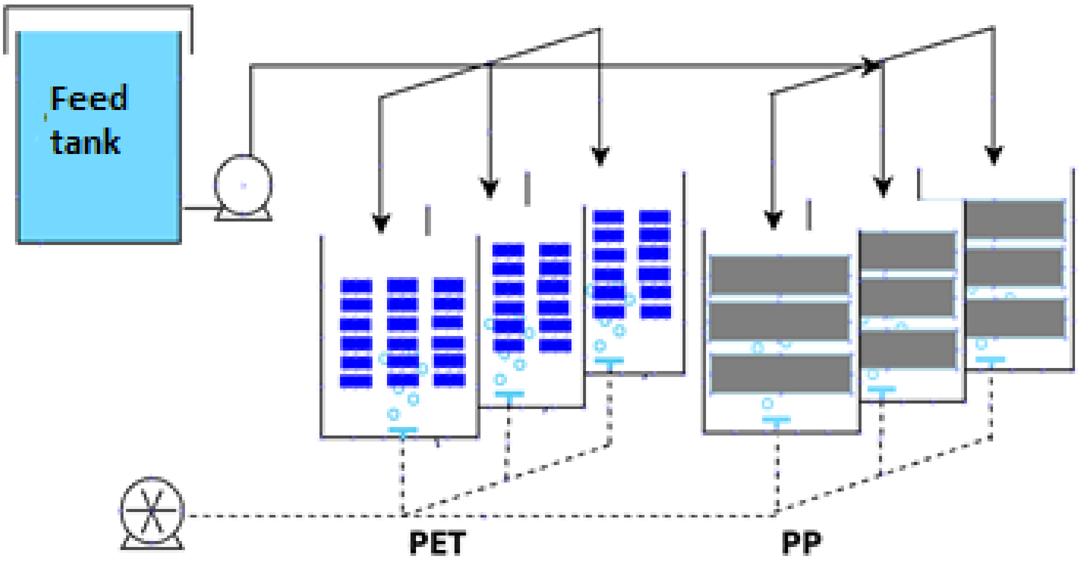

Figure 1. Experimental scheme

2.2 Reactor Operation

The experiments were carried out by triplicated in six experimental bioreactors with capacity of 2.8 L. The substrate was domestic wastewater from an urban sewer, collected and transported to the laboratory once per week for the analysis and experimentation. Reactor characteristics are displayed in Table 1. All reactors were operated in aerobic conditions, in which air supply was constantly supplied trough aereators. The pH was not modified (7.5-8.0), besides, the temperature was operated at room conditions (23 ± 3 ºC).

Table 1. Reactor features

Feature	**PET**	**PP**
Specific surface area (m^2 m^{-3} of media)	658	858
Total height (cm)	34.00	29.00
Height:diameter ratio	3:1	
Volume of material in the reactor (%)	50	
Surface organic load rate (OLR) (g DQO m^{-2} d^{-1})	0.30-5.00	
Volumetric organic load kg DQO m^{-3} d^{-1}	0.11 – 3.77	

The CODs in the influent and effluent was analyzed by colorimetric method 5220B, and volatile suspended solids concentration in the mixed liquour (VSS) was constantly determined (APHA et al., 1999), also volatile suspended solids inmovilized in the materials (VSSi) was determined at the final of the experiments. Biochemical oxygen demand (BOD_5), nitrite (NO_3^-), total nitrogen (N_{total}), total phosphorus (P_{total}), pH and temperature was monitored once per month to know the inlet characteristics of the influent. In addition, the removal efficiency of CODs reached in reactors and the quantity of adhered biomass on the support materials were reported.

The main independent variable manipulated in this study was the organic loading rate (OLR) expressed in g CODs m^2 d^{-1}, according to Ec. (1)

$$\mathrm{OLR} = \frac{\mathrm{Q.\,C_{CODs}}}{\mathrm{A}} \tag{1}$$

Where Q represents the influent flow in L h^{-1}, C_{CODs} is the concentration of the soluble chemical oxygen demand in the effluent expressed in g L^{-1}, and A is the total area of the support material in the reactor in m^2. OLR values were varied between 0.30 to 5 g CODs m^{-2} d^{-1}. To manipulate de OLR, was properly varied the influent flow (Q), previously know the value of CODs, according to equation 1.

3. RESULTS AND DISCUSSION

3.1 Substrate and support materials

The wastewater composition used as substrate is shown in Table 2, these characteristics are within of a low strength wastewater according to Tchobanoglous et al. (2003). During the experimentation, the concentration variation was not strong along the monitored parameters, which was beneficial to control the influent. The main parameter manipulated was the OLR, through the control of the inlet flow according to the equation 1.

Table 2. Substrate utilized

Parameter	Unit	Minimum value	Maximum value
CODs	mg L^{-1}	290	490
BOD_5	mg L^{-1}	112	230
VSS	mg L^{-1}	135	175
N_{total}	mg L^{-1}	22	27
NO_3^-	mg L^{-1}	0	0
P_{total}	mg L^{-1}	3	4
pH	pH scale	7.5-8.0	7.5-8.0

The surface area of the materials are crucial to the attachment of the biomass (Christensson and Welander, 2004). Big surface areas could attach large quantities of biomass to the surface. PET and PP surface areas was calculated as 650 and 880 $m^2.m^{-3}$ respectively. These areas are comparable with commercial support materials, since their values are around 402 to 1200 m^2 m^{-3} (McQuarrie and Boltz, 2011), it is because the commercial materials become from synthetic polymers. Moreover, the mechanical properties are almost the same that the original ones.

3.2 Reactors Performance

Different kinds of fixed and moving biofilms reactors have been assessed for the treatment of wastewater (Naz et al., 2016), many of these studies proposed the manipulation of the OLR, both volumetric or surface loading. In this research, the reactors were operated adding OLR from 0.30 to 5.00 g CODs $m^{-2}d^{-1}$. The Figure 2 shows the applied OLR versus CODs removal efficiency, it can be noticed that efficiency decreases as the OLR is added.

For PP material, efficiencies above 90% are observed for OLRs below 1.00 g CODs $m^{-2}d^{-1}$, efficiencies between 80% and 90% for OLR between 1.00 to 2.50 g CODs $m^{-2}d^{-1}$, and efficiencies between 50% to 63% for OLR up to 3 g CODs m^{-2} d^{-1} were achieved. For PET material, the behaviour was almost the same, particullarly for low OLR charges, it is to say that below 1.00 g CODs $m^{-2}d^{-1}$ efficiencies up to 92% were achieved, between 63% to 85% for OLR between 1 to 3 g CODs m^{-2} d^{-1} and a decrease to 40% for OLR between 3 to 5 g CODs m^{-2} d^{-1}. In general, the efficiency decreased as the OLR was increased. Nevertheless, both materials showed good performance in terms of CODs removal, with a slightly better performance when PP was used. Similarly, in other studies, where commercial support material Kaldnes K1 in moving bed biofilm reactors was evaluated, it was found that as the organic load increases removal efficiency decreases, with OLR of 6, 12, 24, 48 and 96 g COD m^{-2} d^{-1} were obtained removal values of 95.1%, 94.9%, 89.3%, 68.7% and 45.2% respectively (Aygun *et al.* 2008). Bassin *et al.* (2006) tested Kadnes K1 and Mutang Biochip, reached efficiencies of 86% and 73% for OLR of 12.8 g COD m^{-2} d^{-1} respectively, while with OLR down to 3.2 g COD m^{-2} d^{-1} achieved 95% COD removal. Moreover, this study corroborates the study of Schlegel and Koeser (2007), who states that the COD removal is strongly influenced by the organic load supplied.

In other kind of materials, like those based on ceramic in an aerobic double layered submerged reactor, discovering a positive correlation between volumetric organic load provided and COD concentration in the effluent, in other words, as the organic load was added, removal efficiency drops (Osorio and Hontoria, 2002).

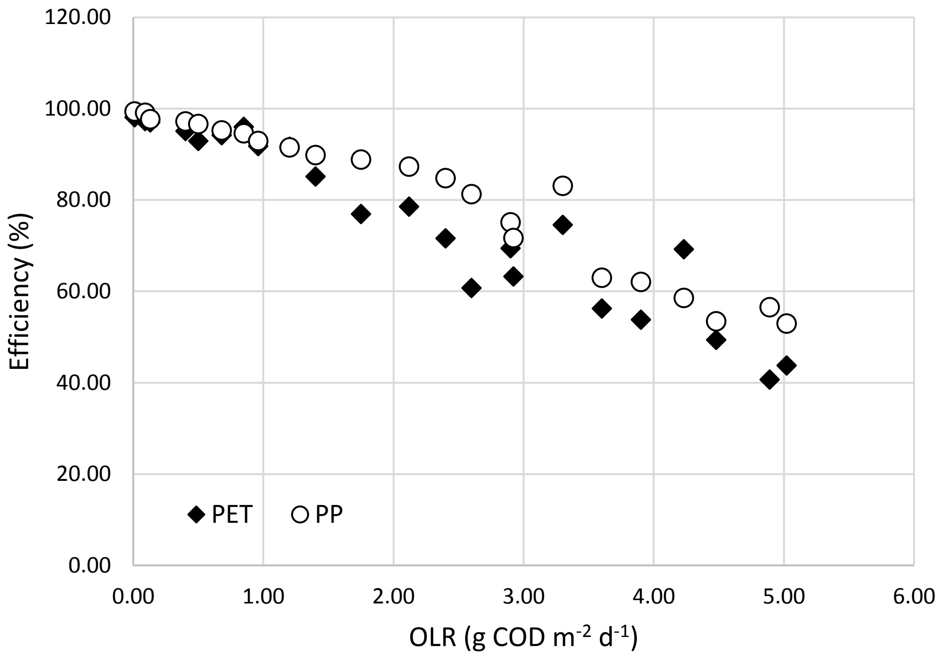

Figure 2. Soluble chemical oxygen demand removal at different surface organic loading

The Figure 3 shows the performance of treatment in terms of COD removed during the time of experimentation. It is noticed that during the first 200 days, the removal efficiency of COD remains up to 80% for PP and up to 69% for PET, however it decreases to 50% and drop to 40% for PP and PET respectively. This behavior is due to the increase in the OLR. In addition, the variability of data is directly related with support materials stability to retain biomass, emphasizing this problem for PET.

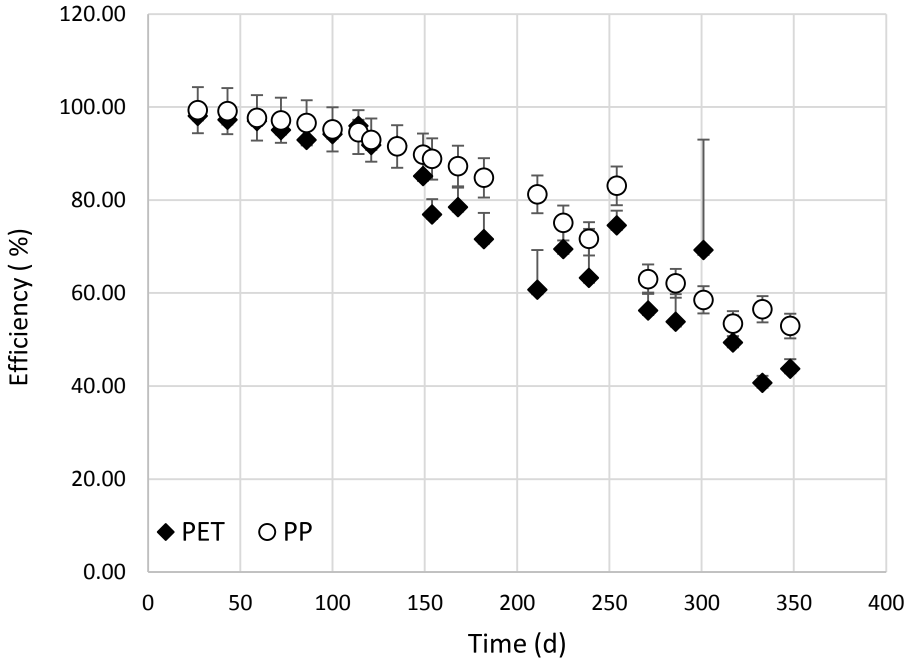

Figure 3. Soluble chemical oxygen demand removal during the experimentation

3.4 Attached biomass to support materials.

Biofilm growth in plastic materials is the result of several processes, such as: absorption, desorption, adherence, bacterial growth and detachment (Peyton and Characklis, 1992). The Figure 4 shows the amount of biomass adhered support materials in each experiment repetition, measured at the end of the experimentation.

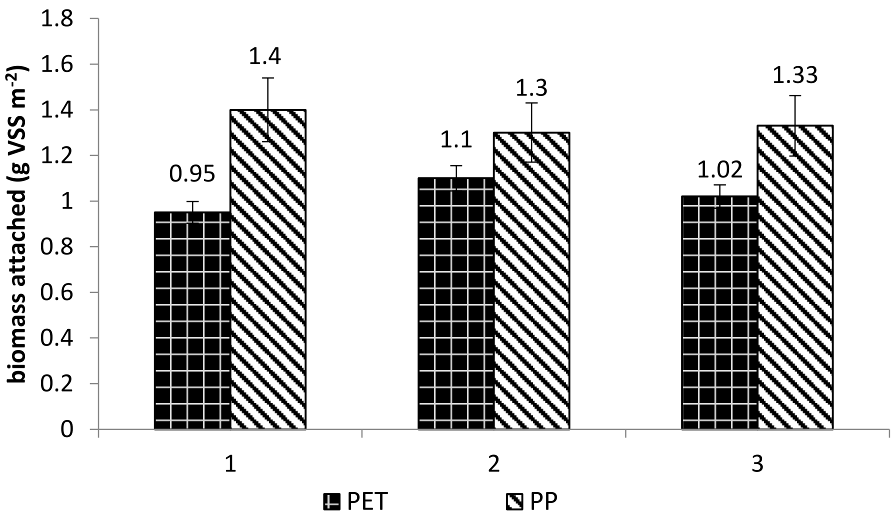

Figure 4. Attached biomass

In average PET material presented 1.023 g SSVi m^{-2}, while PP material 1.34 g SSVi m^{-2}, the PP material presented more quantity of adhered biomass and consequently more removal efficiency. According to Brinkley and Souza (2012), for mobile bed systems (MBBR) was found biomass concentrations in a range of 5 to 25 g TS m^{-2} . Other studies, where two systems of susspended biomass in fixed bed and mobile bed were tested, reported attached biomass from 9.36 to 13.12 g SST m^{-2} (Aygun et al., 2008) in this case the SSV:SST ratio for biomass, is typically in the range between 2.5 and 1.42; values similar to those with lower performance in MBBR systems, in comparison with the present research.

On the other hand, reactors with PET materials had biomass blocking problems, it was notorious that air bubbles could not mobilize freely through the support material, not the case of PP reactors. As for the performance of the average SSV for both groups of reactors, were irregular and different from one another, remarking more variation in its values with the PET material, which has bigger volume of detached biomass, as a result of a probable difficulty of the biomass to attach.

4. CONCLUSIONS

The support materials assessed PET and PP contributed to the growth of biofilm, and can be used in AFBR reactors, whose efficiency depends on the provided OLR. Efficiency was higher than 90% for OLR below 1.00 g CODs $m^{-2}d^{-1}$ and lower than 80% for loads near to 2.5 g CODs m^{-2} d^{-1}.

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