Anaerobic treatment of organic chemical wastewater using packed bed reactors

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Abstract The studied organic chemical wastewater had a high COD, 20–45 g/L, and low TSS, less than 200 mg/L, making anaerobic bio-filtration a suitable treatment method. The organic matter consisted of alcohols, amines, ketones and aromatic compounds, such as toluene and phenol. Granulated activated carbon (GAC) and a porous stone called tezontle, widely available in Mexico, were used as a bio-film support. Once inoculated, the mesophilic reactors with granulated activated carbon (GAC-BFs) reached stability with 80% COD removal in 40 days, while the reactors with tezontle material (tezontle-BF) required 145 days. Biodegradation of more than 95% was obtained with both support media: at organic loads less than 1.7 kg m$^{-3}$ d$^{-1}$ in tezontle-BF and with loads of up to 13.3 kg m$^{-3}$ d$^{-1}$ in GAC-BFs. The bio-filters with GAC allowed COD removal efficiency of 80% at a load as high as 26.3 kg m$^{-3}$ d$^{-1}$, while the same efficiency with tezontle was obtained at loads up to 4.45 kg m$^{-3}$ d$^{-1}$. The use of GAC as support material allows greater biodegradation rates than tezontle and it makes the bio-filters more resistant to organic increases, inhibition effects and toxicity. Methanogenic activity was inhibited at loads higher than 1.7 kg m$^{-3}$ d$^{-1}$ in bio-filters with tezontle and 22.8 kg m$^{-3}$ d$^{-1}$ in bio-filters with GAC. At loads lower than the previously mentioned, high methane production yield was obtained, 0.32–0.35 m$^3$CH$_4$/kg COD$_{removed}$. The biomass growth rates were low in the bio-filters with both kinds of material; however, a sufficiently high biomass holdup was obtained.

Keywords Activated carbon; anaerobic; industrial wastewater; packed bed reactors; tezontle

Introduction

Industrial organic chemical wastewater contains compounds resistant to biological degradation with inhibitory and toxic effects for the bacteria performing organic matter degradation. Recent studies have shown that anaerobic bio-reactors are able to remove many xenobiotic compounds (Van Lier et al., 2001). Anaerobic treatment has high potential for the elimination of halogenated organics, nitro-aromates and azo dyes. However, anaerobic biodegradation rates for some chemical effluents are lower compared with the aerobic rates and they depend on wastewater compositions, reactor design or arrangement and on the operational conditions (Levin and Gealt, 1997). The anaerobic reactor effectiveness can be enhanced by biomass immobilization on support media, reaching this way higher biomass concentration in the reactor. In addition, volatile organic chemicals present in the primary effluent are partially or substantially volatilized into the air when aerobic biodegradation is used. A treatment system with coupled sorption and anaerobic stabilization processes, installed before the aerobic reactor, can mitigate these problems. The studied organic synthesis wastewater had a high COD, 20–45 g/L, and low TSS, less than 200 mg/L, making anaerobic bio-filtration a suitable treatment method. Stationary packed bed processes are more vulnerable to clogging problems than fluidized bed reactors but they are less energy consuming. Media plugging, pressure drop and channeling problems can be avoided with a good support selection, correct system design and operation. The organic matter in the studied wastewater consisted of alcohols, amines, ketones, toluene and phenol. The presence of xenobiotics was the reason to suggest the use of granular...
activated carbon (GAC) as support media. The GAC surface properties and high sorption capacity makes it a suitable material for biofilm attachment media providing an advantage for application to the treatment of toxic or inhibitory wastewater (Khan et al., 1982; Gardner et al., 1988; Fox et al., 1990). If the toxicant is adsorbable on the carbon, low toxicant concentration can be maintained in the bulk liquid and biomass exposure to the toxicant may be reduced. There are reports concerning the use of GAC in fluidized bed anaerobic reactors to remove catechols (Suidan et al., 1980), polycyclic compounds (Wang et al., 1984), phenols (Wang et al., 1986) and 2,4,6-trinitrotoluene (Monteleb et al., 2001); in the treatment of coal gasification wastewater (Suidan et al., 1983; Fox et al., 1988; Nakhla et al., 1990), of metal-cuttings fluids wastewater (Kim et al., 1989) and of landfill leachates (Suidan et al., 1993; Kupferle et al., 1995). Bio-filtration using mineral and vegetable GAC with different granulometric characteristics has already been tested with chemical-pharmaceutical effluents, obtaining the best performance when mineral GAC with grain diameter of 1–2 mm was used and demonstrating the GAC’s advantage over anthracite as a support material (Nacheva et al., 1998). The objective of this study was to determine the feasibility of anaerobic bio-filtration as a treatment method for the effluent of an organic synthesis industry, testing as a bio-film support granulated activated carbon and a porous stone called tezontle which is widely available in Mexico. Operation and design parameters for the bio-filtration system were obtained. Special emphasis was placed on the bio-film development and acclimation to the specific wastewater substrate at different organic loads and on the inhibition effects caused by the xenobiotic compounds.

**Methods**

**Experimental setup and support materials**

Four laboratory upflow bio-filters were used (Figure 1). Each reactor consisted of a jacketed acrylic column (10.3 cm diameter and 1.27 m high) with a total volume of 9.4 L and an effective volume (fixed bed) of 7.5 L, with recycling, feed and gas collection systems. Water was recycled through an acrylic jacket that kept the reactor temperature at 35°C. The column overflow was directed in an upflow mode to an external settler, from the bottom of which it was recycled using a peristaltic pump. The effluent was collected from the top of the sedimentation recipient. Gas produced in the reactor was received in an inverted acrylic tube collector. Tezontle, a volcanic porous stone, was

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**Figure 1** Schematic diagram of the anaerobic bio-filtration system: 1- anaerobic filtration reactor; 2- settler; 3- gas collector; 4- heating water bath with temperature controller; 5- feed tank; 6- effluent container; 7- feed pump; 8- recycle pump; 9- sampler; 10- hot water recycling pump
used to immobilize and retain cells in the first reactor (BF1), while lignite GAC (Clarimex CAGR 8 × 30) was used in the three other reactors (BF2, BF3 and BF4). Grain size was of 2.00–2.38 mm for both tested materials. Mineral GAC was sieved to select a fraction of mesh No. 8–10, which corresponds to the grain size indicated above, then washed with water and dried. Particle density was determined of 0.919 t/m³, apparent density of 0.439 t/m³, carbon bed voidage of 52.2% and bed pore volume of 1.2 mL/g. Pore diameter, surface area, iodine number and activity to molasses were provided by the fabricant, 56 Å, 650 m²/g, 600 mg I₂/g and 102% respectively. The carbon used is of relatively large pores and has the ability to adsorb high-molecular weight substances.

There are different kinds of tezontle in Mexico; two of them, red and black, were evaluated and the red one was selected because of its higher pore volume. Tezontle was previously ground and the mesh No. 8–10 fraction was selected. Particle density of this material was determined to be of 0.892 t/m³, apparent density of 0.472 t/m³, bed media voidage of 47.12%, bed pore volume of 1.0 mL/g and specific bed area of 2,085 m²/m³.

Wastewater and nutrients
The studied wastewater contains large quantities of dissolved organic matter and inorganic salts, with a conductivity of more than 35,000 µS/cm. Industrial scale evaporation-condensation process is used to reduce the conductivity to 1,500–1,800 µS/cm, but this pretreatment does not reduce the COD because of the volatility of the organic constituents. The studied wastewater, after the mentioned pretreatment, had a COD concentration of 20–45 g/L and the organic matter was constituted of alcohols, aldehydes, amines, ketones and aromatic compounds. Some toxic organics were determined to be present, such as toluene (407–696 mg/L) and phenol (102–172 mg/L). Nitrogen concentration was high, 204–1,897 mg/L as TKN, most of it being organic nitrogen, 144–1,366 mg/L. Phosphates ranged from 0.1 to 4 mg/L. Total suspended solids were between 156 and 178 mg/L. Phosphorus and micronutrient were added during all the experimentation. The ratio COD:N:P was controlled to be 450:7:1. Nitrogen was only supplemented when the wastewater with the highest COD concentration was tested. The addition of Fe, Ni, Co and Mo was made based on the following rates: 1, 0.15, 0.1 and 0.002 mg/gCOD respectively. The micronutrients Zn, Mn and Cu were added at 2, 0.7 and 0.3 µg/gCOD. Addition of Na, K, Ca and Mg was based on 5, 20, 13 and 10 mg/gCOD respectively. During a significant portion of the study the feed water was supplemented with yeast.

Experimental procedure
Preliminary experiments were carried out in order to determine and compare the adsorption characteristics and the isotherms of both materials used. Inoculation of the reactors was made with sludge taken from an UASB reactor for domestic wastewater treatment. The inocula were added to the experimental bio-filters together with the support material and left to repose for one day, after which recirculation and feeding were started. Feeding began at a low volumetric organic load (VOL) using dilution with household wastewater and yeast addition. During startup, the industrial effluent had a COD concentration between 20.1 and 23.58 g/L. Once the process was stabilized, gradual increasing of the organic load was practiced, evaluating the biomass acclimation, development and process performance. During this stage dilution was progressively reduced and finally eliminated. The duration of the phases and the operational parameters are summarized in Table 1. After this, bio-filter performance was studied over a wide range of organic loading conditions using wastewater with different COD concentration (CODᵢ), gradually increasing the organic loads and decreasing the hydraulic residence time (HRT), as indicated in Table 2. The three bio-filters with GAC were put at different operational
Table 1 Operating parameters for bio-filters during the startup and biofilm development stages

<table>
<thead>
<tr>
<th>Stage</th>
<th>Period, days</th>
<th>Duration, days</th>
<th>COD, g/L</th>
<th>Volumetric organic load, kg COD m⁻³ d⁻¹</th>
<th>HRT, days</th>
<th>Dilution, %</th>
<th>Industrial portion of VOL, %</th>
<th>Yeast portion of VOL, %</th>
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<td><strong>Startup</strong></td>
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<td></td>
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<tr>
<td>1 – 56</td>
<td>56</td>
<td>1.55 – 1.82</td>
<td>0.082 – 0.100</td>
<td>18.1 – 20.9</td>
<td>7,180</td>
<td>22 – 36</td>
<td>49 – 60</td>
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<td>57 – 73</td>
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<td>4,100</td>
<td>36 – 46</td>
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<td>47</td>
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<td><strong>Biofilm development and acclimation</strong></td>
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<td>150 – 158</td>
<td>8</td>
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<td>0.184 – 0.224</td>
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<td>0.420</td>
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<td>241 – 247</td>
<td>6</td>
<td>10.24</td>
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<td>18.3</td>
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<td>90</td>
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<td>12.54</td>
<td>0.68</td>
<td>18.3</td>
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<td>92</td>
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<td>14.35</td>
<td>0.784</td>
<td>18.3</td>
<td>150</td>
<td>93</td>
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<td>18.60</td>
<td>1.016</td>
<td>18.3</td>
<td>114</td>
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<td>5</td>
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<td>22.98</td>
<td>1.256</td>
<td>18.3</td>
<td>0</td>
<td>99.8</td>
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</table>
conditions and kinetic parameters were determined. The temperature was held at 35\(^\circ\)C during the entire experimentation. Acclimation to each loading rate was assumed to be complete when constant gas production and a high COD removal efficiency (more than 75\%) were attained, achieving a pH between 6.5 and 8.5.

**Analytical methods**

Organic matter, as a COD concentration, was determined in the influent and effluent from the bio-filters daily. Temperature, pH and biogas generation were also monitored daily. Biogas composition was determined periodically by gas chromatography using a thermal conductivity detector. Volatile fatty acids (VFA) were controlled weekly based on alkalinity determination at pH of 4.3 and 5.75. Gas chromatography analysis for VFA, using a flame ionization detector, was performed periodically. SST and SSV in the effluent were also determined once a week. Organic nitrogen, NH\(_4\)-N and P were determined for each operational phase. Biomass quantification in the fixed bed, based on SSV determination, was conducted at the end of each experimental phase. Samples of 30–50 ml were taken from the middle of each column; they were first added to distilled water in order to remove unattached particles and then transferred to a salinity solution, where biomass was detached mechanically. Volatile suspended solids were determined in both solutions and biomass was calculated as mg VSS per liter of liquid phase. Biomass-free grains were returned to the upper zone of their respective bio-filters. Analytical measurements of COD, TSS, VSS, N and P were done according to *Standard Methods for Examination of Water and Wastewater* (1998).

**Results and discussion**

**Startup and stabilization period**

*Adsorption capacity of support materials.* Adsorption on GAC was evaluated obtaining Freundlich isotherms for COD. The adsorption coefficients \( k \) and \( n \) were 0.007 mg\(^{1-1/0.146}\) L\(^{0.146}\) g\(^{-1}\) and 0.146 respectively. The low values indicate a very complex water composition and presence of substances of low adsorbability. It was determined that only 30\% of COD can be considered as easily adsorbable organic matter, which can be attributed to the aromatic compounds present in the wastewater, since alcohols, aldehydes, amines, ketones are low adsorbable groups. Tezontle did not have any adsorption capacity for the organic matter present in the studied wastewater.
Startup and stabilization period. Once inoculated, the bio-filters with GAC reached stability with a COD removal of 80% in 40 days, while the bio-filter with tezontle required almost 146 days (Figure 2a). This can be attributed to the higher adsorption capacity of the GAC, due to which the load and the inhibitory effects are reduced and the biomass capacity of degradation increases. During the startup period, the increases of the organic load to the GAC-BFs of 13.45% produced 15–31% falls in process efficiency. The decreases in efficiency were less marked over time, from 31% with the first increase, to 15–20% after two months of operation. The COD removal efficiency at the end of the 149 days period was of 92%. At startup conditions of the tezontle-BF, 70% COD removal was seen at day 57, when a load increase of 21% was applied and drastic destabilization of the process was observed for several days. By day 73, the tezontle system was capable of accepting increases in load without major perturbations in the process and this ability was further strengthened over time. However, stable conditions and good biogas production were not obtained until day 146 when the COD removal reached 90.55%.

Biomass development. After 5 months from the startup, increases of 20–40% in the VOL produced small falls in the process efficiency of bio-filters with both materials (Figure 2b). The decreases observed were of 5–20%, with a relatively quick recovery of 5–10 days. After 7.7 months of operations, the GAC and tezontle bio-filters were more resistant to increases in the organic load: increases in the range of 23–41% of the previous load were causing only slight decreases of 1–3% in the efficiency. For VOL of 0.18–1.02 kg m⁻³ d⁻¹ with an HRT of 18.3 days, the efficiencies obtained with GAC-BFs and tezontle-BF were similar (94–99%), with a slight predominance of the GAC BFs of 1–2%. During this period pH and alkalinity in the reactors increased, from 6.5–6.9 to 7.5–8.0 and from 430–710 mg CaCO₃/L to 1,850–2,195 mg CaCO₃/L respectively. Biogas production reached 0.385 m³/kg CODrem at day 243, 78% methane was determined in GAC-BFs and 71% in tezontle-BF. Volatile fatty acids concentrations were almost constant in the range of 50–100 mg/L. Biomass increased from 2.4 kg/m³ (day 150) to 5.2 kg/m³ (day 300) in the tezontle-BF and from 2.7 to 5.9 kg/m³ as averages in the GAC-BFs. Observations of the physical characteristics of the solids...
within the filters indicated that not all of them were attached to the surface of the medium; there were many not attached dense flocs in the void spaces. Not attached VSS were estimated to be almost 20% of the total VSS in the bio-filters on day 300. Effluent TSS also increased from 50–160 mg/L (day 150) to 280–360 mg/L (day 300).

Biodegradation rates and kinetic parameters. On day 290 dilution and yeast addition were stopped and industrial wastewater with a COD of 23 g/L was fed to all reactors at a load of 1.256 kg m$^{-3}$ d$^{-1}$. Bio-filter performance during the evaluation period (days 300–795) is presented on Figure 3. GAC-BFs showed stable performance and good resistance to load increases, while tezontle-BF was very sensitive and after each increase the system needed 7–10 days to reach stability again. The reductions of COD removal efficiency were accompanied with falls of the biogas generation which required additional 2–3 days to reach maximum biogas production. This recovering phenomenon needed only 1–2 days in GAC-BFs. The increase of wastewater COD concentration from 22.98 to 44.95 g/L did not cause negative effects on the bio-filter performance. The COD removal rate in GAC-BFs increased with the gradual increase of the VOL and reached values of 20–21 kg m$^{-3}$ d$^{-1}$ on day 674. Similar increase of the daily biogas production was observed. The methane content of the biogas was approximately 86% until day 673. From day 674 onward CH$_4$ content decreased, reaching 78% on day 744. This means that VOL more than 22.8 kg m$^{-3}$ d$^{-1}$ caused inhibition to methane production in GAC-BFs. The calculated methane production yields were 0.33–0.35 m$^3$CH$_4$/kg COD$_{removed}$ for VOL less than 22.8 kg m$^{-3}$ d$^{-1}$.

Tezontle-BF reached removal rates of only 5.5 kg m$^{-3}$ d$^{-1}$ on day 600 (VOL of 8.39 kg m$^{-3}$ d$^{-1}$) and the following load increases resulted in strong efficiency reduction. Biogas generation was also drastically reduced after day 626 when VOL of 10.2 kg m$^{-3}$ d$^{-1}$ was applied. Biogas was practically not produced from day 715 onward. Methane content was almost 85% until day 394 (VOL of 1.72 kg m$^{-3}$ d$^{-1}$). After the increase of VOL to 2.4 kg m$^{-3}$ d$^{-1}$, the methane content began to decrease and it was determined to be 55% (day 592) at VOL of 5.99 kg m$^{-3}$ d$^{-1}$ and 42% (day 620) at VOL of 8.39 kg m$^{-3}$ d$^{-1}$. The calculated methane production yields were 0.32–0.34 m$^3$CH$_4$/kg COD$_{removed}$ for VOL less than 1.7 kg m$^{-3}$ d$^{-1}$. Volatile fatty acids in the effluents had a concentration of between 57 and 187 mg/L; higher concentrations were determined at higher organic loads in the last experimental phases. Alkalinity was relatively high during all the experimental period, between 1,980 and 2,950 mg/L. Sulfide concentration varied from 14 to 32 mg/L. Nitrogen removal was determined to be of 93% for organic nitrogen and 48–52% for TKN.

![Figure 3](https://iwaponline.com/wst/article-pdf/54/10/67/431072/67.pdf)

**Figure 3** Removal of COD and biodegradation rates obtained in the bio-filters
The concentration of VSS in the bio-filter effluent was 205 ± 30 mg/L on day 300. During the experimentation VSS increased slowly presenting values of 354 ± 35 mg/L on day 490 and 370 mg/L on day 625. From this day onward VSS began to decrease reaching 290 ± 37 mg/L on day 752. The results of biomass measurements carried out on samples withdrawn from the bio-filters are presented in Figure 4. Detached biomass had been accumulating in the media and as can be seen, bio-filters had the ability to retain a very high biomass holdup. Over time the proportion of not attached biomass trapped in the media bed increased from 20% to almost 45%. The rate VSS/TSS also increased during operation from 0.75 to 0.83. The greatest biomass growth and solids accumulation were observed in BF4 which was operated at the highest organic loads. Solids concentration of 15.2 kgTSS/m³ was determined on day 752. At that time clogging effects, channeling and difficulties in the recirculation, as well as gas bubble trapping in the media bed and efficiency reduction of 5%, were observed in BF4. Backwashing and purging of solids was practiced, after which the hydraulic conditions and the efficiency were recovered. The TSS concentration determined after washing was 11.8 kg/m³. Solid concentration of 15.3 kgTSS/m³ was reached in BF3 on day 773. The same problems as in BF4 were observed. After washing and solid purging, TSS were reduced to 12.0 kg/m³ and BF3 turned to normality. Similar difficulties were noticed in BF2 on day 773 when TSS was 14.6 kg/m³. BF1 did not present these problems until the end of the evaluation, but TSS was no more than 11.9 kg/m³. Washings practiced in BF3 and BF4 reduced not attached solid proportion to 30%, which did not affect removal efficiency. The attached biomass portion was higher in tezontle-BF compared with GAC-BFs.

Based on the results, relationships between operation parameters (VOL, HRT) and COD removal efficiency were obtained (Figure 5). As can be seen, removal efficiencies in tezontle and GAC bio-filters are similar only up to a load of 1.72 kg m⁻³ d⁻¹ (only 1–2% greater in GAC-BFs). More than 95% of COD removal can be obtained in GAC-BFs with VOL up to 13.78 kg m⁻³ d⁻¹, while the same result can be obtained with a load up to
1.72 kg m$^{-3}$ d$^{-1}$ in tezontle-BF. GAC-BFs allowed 80% COD removal with VOL of 26.32 kg m$^{-3}$ d$^{-1}$, while the same removal was obtained at VOL of 4.45 kg m$^{-3}$ d$^{-1}$ in tezontle-BF. The needed biomass quantity to achieve these results was lower than the one which caused clogging effects. Obtained relationships suggest VOL as a better design parameter compared with HRT; however, for GAC-BFs both of them can be used; the effect of the wastewater COD variation was not so pronounced in GAC-BFs. Removal efficiencies of 80–90% were obtained with HRT of 7.1–9.5 d in tezontle-BF and with 1.0–1.4 d in GAC-BFs. Maximum COD removal efficiency of 97.9% was obtained in tezontle-BF at VOL of 1.26 kg m$^{-3}$ d$^{-1}$ and HRT of 18.3 d. Efficiencies of 98.1–99.2% were obtained in GAC-BFs at VOL of 1.26–8.39 kg m$^{-3}$ d$^{-1}$ and HRT of 5.4–18.3 d. Figure 6 shows the COD removal obtained in tezontle-BF versus the organic load per m$^2$ of medium surface which permits to extrapolate obtained results to tezontle material with different porosity and specific area. Anaerobic bio-filters, with both GAC and tezontle, did not require addition or exchange of support material during the entire experimental period.

The determination of biodegradation kinetics was based on the consideration that as a great proportion of the active biomass in the BF were present in not attached form, the process can be analyzed in a manner similar to the suspended growth system. Using Monod’s kinetic equation and the steady state results from bio-filters at different organic loads, the kinetic coefficients were obtained (Table 3).

Biodegradation rate coefficient in GAC-BFs is 4.4 times greater than the one in tezontle-BF, while $K_r$ is 3 times higher. Biomass growth yields are similar using both kinds of material but due to the higher removal rate, the maximum specific growth rate in GAC-BFs is greater than the one in tezontle-BF. The obtained values indicate that the biomass growth yields are very low in both GAC and tezontle bio-filters, compared with growth yields reported for anaerobic reactors. This can be attributed to the wastewater composition, as xenobiotic compounds do not favor the microorganism growth. Therefore, the high biomass retention capacity of the bio-filters becomes a great advantage in the treatment of these kinds of wastewaters.

### Figure 6
Relationships between surface organic load (SOL) and COD removal efficiency obtained for the best performance range in tezontle-BF and between organic load (OL) per kg of GAC and efficiency obtained in GAC-BFs

### Table 3
Comparison of kinetic coefficients obtained for bio-filters with tezontle and GAC support media

<table>
<thead>
<tr>
<th>Kinetic coefficients</th>
<th>Tezontle-BF</th>
<th>GAC-BFs</th>
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<tbody>
<tr>
<td>$k$, g COD.gVSS$^{-1}$ d$^{-1}$</td>
<td>0.592</td>
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<tr>
<td>$K_r$, mg/L</td>
<td>762</td>
<td>2383</td>
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<tr>
<td>$Y$, g VSS/g COD$_{nom}$</td>
<td>0.0287</td>
<td>0.0291</td>
</tr>
<tr>
<td>$k_d$, d$^{-1}$</td>
<td>0.0053</td>
<td>0.0034</td>
</tr>
<tr>
<td>$\mu_{\max}$, d$^{-1}$</td>
<td>0.0170</td>
<td>0.0744</td>
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</tbody>
</table>

$k$ – biodegradation rate coefficient; $K_r$ – half-velocity coefficient; $Y$ – cell yield coefficient; $k_d$ – endogenous decay coefficient; $\mu_{\max}$ – maximum specific growth rate
Conclusions
Anaerobic mesophilic packed bed reactors with GAC and tezontle media can be used for the treatment of high strength organic chemical wastewater with COD of 20-45 g/L, which contains xenobiotic compounds. The startup is almost four times shorter in GAC-BFs. Bio-filter performance is strongly dependent on the organic load. Biodegradation of more than 95% can be achieved with both support media at organic loads less than 1.7 kg m$^{-3}$ d$^{-1}$ in tezontle-BF and with loads up to 13.3 kg m$^{-3}$ d$^{-1}$ in GAC-BF. The bio-filters with GAC allow an 80% COD removal at a load as high as 26.3 kg m$^{-3}$ d$^{-1}$, while the same efficiency with tezontle can only be obtained at VOL up to 4.45 kg m$^{-3}$ d$^{-1}$. The use of GAC as support material can increase the biodegradation capacity of the packed bed reactor more than six times. Inhibition and toxicity effects disable bio-filters with tezontle at a load higher than 6.0 kg m$^{-3}$ d$^{-1}$, while the tolerance of bio-filters with GAC is 4.7 times greater. Inhibition of methanogenic activity is detected at loads higher than 1.7 kg m$^{-3}$ d$^{-1}$ in bio-filters with tezontle and 22.8 kg m$^{-3}$ d$^{-1}$ in bio-filters with GAC. At loads lower than previously mentioned, high methane production yield can be obtained, 0.32–0.35 m$^3$CH$_4$/kg COD$_{removed}$. Bio-filters with GAC are more resistant to organic load increases. The biomass growth rates are low in bio-filters with both kinds of material, yet a sufficiently high biomass holdup can be obtained. The biomass concentration needed to achieve optimal removal is lower than the one at which clogging occurs; however, periodic backwashing has to be practiced to remove the excess of retained solids.

References

