Simultaneous degradation of phenolic compounds under denitrifying conditions in a UASB reactor provided with granular activated carbon

Degradación simultánea de compuestos fenólicos bajo condiciones desnitrificantes en un reactor UASB provisto con carbón activado granular

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ABSTRACT

This work studied the removal capacity of a mixture of phenolic compounds (phenol, *p*-cresol, *o*-cresol) by denitrification; in addition, the effect of granular activated carbon (GAC) in the process carried out in UASB (up-flow anaerobic sludge blanket) reactors. The organic load was increased from 450 to 3250 mg C L^{-1}d^{-1} by adjusting the HRT from 2 to 0.25 d in the reactor with GAC and the control reactor without GAC. The removal efficiencies of phenolic compounds increased as the organic load increased, obtaining values from 89.7 % to 95.5 % in the reactor without GAC and 95.8 % to 99.1 % in the reactor with GAC. The nitrate removal in the reactor with GAC reached 79.3 % to 98.0 % efficiencies, while the control obtained 64.8 % to 96.9 %. Finally, the maximum capacities of GAC were evaluated by adsorption isotherms, obtaining the following values (mg g^{-1}): 164.6 for *o*-cresol, 134.5 for *p*-cresol, 110.7 for phenol, and 44.4 for nitrate. The results show the capacity of a denitrification process to remove a mixture of phenolic compounds. In addition, the reactor with GAC increased the removal efficiency of all compounds.
Keywords: *phenolic compounds; activated carbon; adsorption isotherms; UASB reactor.*

RESUMEN

El presente trabajo, estudió la capacidad de eliminación de una mezcla de compuestos fenólicos (fenol, *p*-cresol, *o*-cresol) por vía desnitrificante; además, el efecto del carbón activado granular (CAG) en el proceso realizado en reactores UASB (up-flow anaerobic sludge blanket). La carga orgánica se fue incrementando de 450 a 3250 mg C L^{-1}d^{-1}, mediante el ajuste del TRH de 2 a 0.25 d en el reactor con CAG y en el reactor control sin CAG. Las eficiencias de eliminación de los compuestos fenólicos aumentaron a medida que se incrementó la carga orgánica, obteniéndose valores del 89.7 % al 95.5 % en el reactor sin CAG, y del 95.8 al 99.1 % en el reactor con CAG. Para la eliminación de nitrato, el reactor con CAG alcanzó eficiencias de 79.3 % a 98.0 %, mientras que el control obtuvo 64.8 % a 96.9 %. Finalmente, se evaluaron las capacidades máximas del CAG mediante isotermas de adsorción, obteniéndose los siguientes valores (mg g^{-1}): 164.6

para *o*-cresol, 134.5 para *p*-cresol, 110.7 para fenol y 44.4 para nitrato. Los resultados muestran la capacidad de un proceso desnitrificante de eliminar simultáneamente una mezcla de compuestos fenólicos, además, se observó que el CAG incrementó la eficiencia eliminación de todos los compuestos.
Palabras clave: *compuestos fenólicos; carbón activado; isotermas de adsorción; reactor UASB.*

INTRODUCTION

Most effluents from industrial processes, especially petrochemical industries, significantly impact the environment (Hamdaoui and Naffrechoux, 2007; Pavithra *et al*., 2023). Due to the harmful substances from the oil and refining processes involved, the discharges from these industries contain large amounts of phenolic compounds (Dąbrowsky *et al*., 2005; Al Bsoul *et al*., 2021; Zhou and Nemati, 2022). Recently, new strategies for removing or biodegrading various phenolic compounds and their isomers have been studied by coupling different biological and physical processes. The removal of phenolic compounds is critical because they have been considered priority pollutants (Al Bsoul *et al*., 2021; Said *et al*., 2021). It is necessary to develop treatments to minimize the toxicity of these compounds, preferably using alternatives that are friendly to the environment and have low operating costs (González *et al*., 2013; Panigrahy *et al*., 2020; Ahmaruzzaman *et al*., 2024) that can be achieved through biodegradation since biological processes are suitable to remove organic contaminants at low cost (Mahdavianpour *et al*., 2018; Yan *et al*., 2021; Hernandez *et al*., 2024).

Many microorganisms can metabolize aromatic compounds, including anaerobic fungi, bacillus bacteria, and denitrifying bacteria (Singh *et al*., 2020). Denitrifying bacteria can oxidize different organic compounds, including some highly recalcitrant contaminants such as phenol, *o*-cresol, *p*-cresol, and *m*-cresol, among others (Liu *et al*., 2016; Han *et al*., 2020; Singh *et al*., 2020; Feng *et al*., 2023). Organotrophic denitrification provides a feasible alternative to the petrochemical industry, because their effluents contain significant concentrations of nitrogen and phenolic compounds, which can be biodegraded following this metabolic pathway and,

at best, can be entirely removed (Meza *et al.*, 2008; González *et al.*, 2013).

On the other hand, adsorption is a process that is widely used in water treatment systems. Adsorption in carbonaceous materials is complicated by the interplay of several factors affecting the adsorption capacity: concentration, type of functional group and their location and distribution on the surface, pore size distribution, and pore connectivity (Liu *et al.*, 2017; Ahmaruzzaman *et al.*, 2024). Activated carbons have proper adsorption capacity for various organic compounds, such as phenolic compounds from different types of water (Said *et al.*, 2021; Pavithra *et al.*, 2023). Despite this, studies on treating these effluents have focused on using a single phenolic compound, which limits the understanding of the process compared to a real effluent. Thus, the objective of the present study was to evaluate the simultaneous biodegradation capacity of three phenolic compounds (phenol, *p*-cresol, *o*-cresol) by a denitrifying consortium in a UASB (Upflow Anaerobic Sludge Blanket) reactor, as well as the effect of the application of granular activated carbon (GAC) in the process. In addition, the present study describes the adsorption behavior of phenolic compounds through adsorption isotherms obtained from batch experiments, adjusting to the Freundlich and Langmuir equations for calculating the adsorption parameters.

MATERIALS AND METHODS

Anaerobic consortium and GAC

A 0.7 L UASB reactor was inoculated with 20 g volatile suspended solids (VSS) L^{-1} of anaerobic granular sludge from a biologic process in a full-scale UASB reactor installed in a brewery factory in Cd. Obregón, Mexico. The acclimatization period consisted of feeding a mix of phenolic compounds: phenol, *p*-cresol, *o*-cresol, and nitrate as electron acceptors (C/N ratio of 1.08), with a hydraulic residence time (HRT) of 48 h. After two months, the reactor reached a chemical oxygen demand (COD) removal efficiency of 88 % for phenolic compounds and 80 % for nitrate. The acclimatized sludge was used to inoculate two reactors, as described in the following section.

The GAC used was activated charcoal (Sigma-Aldrich, Darco® 242268) with a particle size of 20-40 mesh (~400-800 mm), a total pore volume of 0.95 mL/g, and a total surface area of 650 m²/g, according to the technical sheet of the supplier. The GAC was washed twice with distilled water to remove fine powder particles; then, it was dried in an oven at 60 °C for 12 h before its use.

UASB reactor operated with and without GAC

After reaching the steady state to acclimate the sludge, two laboratory-scale UASB glass reactors of 0.7 L (35 cm height, 5.9 cm diameter) were inoculated with 10 g VSS L^{-1} of an anaerobic consortium. A reactor was supplemented with 20 g L^{-1} of GAC, and the control reactor was operated without GAC. The reactors were bottom-fed using synthetic solutions with phenolic compounds and nitrate, respectively. The solution

used as carbon source was composed with (g L^{-1}): *p*-cresol (0.036), *o*-cresol (0.0652), phenol (0.0385), K_2HPO_4 (3.2), KH_2PO_4 (1.2), and $MgCl_2 \cdot 6H_2O$ (0.4). The solution with nitrate was composed of $NaNO_3$ (2.46 g L^{-1}), Na_2SO_4 (2 g L^{-1}), and 2 mL L^{-1} of trace element solution, which composition was as follows (mg L^{-1}): $FeCl_3 \cdot 6H_2O$ (30), $CaCl_2 \cdot 2H_2O$ (600), $Na_2MoO_4 \cdot 2H_2O$ (120), $CuSO_4 \cdot 5H_2O$ (20). The reactors were operated at room temperature (~25 °C). The performance of the reactors was evaluated in the four stages described in Table 1.

The influent and effluent samples were taken to analyze the performance of reactors, sampling daily in stages 1 and 2 and every third day in stages 3 and 4. The removal efficiency of phenolic compounds and nitrate was obtained with the following equation:

$$Efficiency\ (\%) = \frac{C_o - C_f}{C_o} \ x\ 100$$
(1)

where C_o and C_f are the initial and final concentrations of each compound in the solution (mg L^{-1}), respectively.

Adsorption of phenolic compounds and nitrate on GAC

Adsorption experiments were conducted to identify the capacity of GAC to adsorb the three phenolic compounds and nitrate. A fixed amount of GAC (0.12 g) was added to an aqueous solution (0.04 L) containing 0-1 g L^{-1} of each compound (phenol, *p*-cresol, and *o*-cresol) in a stoppered 50 mL flask. The flasks were shaken at 150 rpm and 25 °C for 72 h to achieve adsorption equilibrium. The concentration of each compound in the mixtures was measured using the spectrophotometric method (Spectroquant Pharo 300) at 271, 291, and 500 nm for phenol, *p*-cresol, and *o*-cresol, respectively. The remaining concentration was measured in each solution to obtain the equilibrium adsorption capacity of the adsorbent (mg g^{-1}):

$$q_e = \frac{(C_o - C_e)V}{m}$$
(2)

where q_e is the adsorption capacity of the adsorbent at equilibrium (mg g^{-1}), V is the volume of solution (L), C_e is the equilibrium concentration of each aromatic compound in the solution (mg L^{-1}), and m is the mass of GAC (g).

The experimental results from the equilibrium studies were adjusted for different isotherm models to find the best to represent these experimental data. The models used were

Table 1. Operational periods in UASB reactors to treat phenolic compounds and nitrate.
Tabla 1. Periodos de operación en los reactores UASB para tratar compuestos fenólicos y nitrato.

Period	HRT (days)	Organic Load (mg C L^{-1} d^{-1})	Inlet flow (L)	Period (days)
1	2	450	0.345	56
2	0.8	1116	0.915	8
3	0.5	1626	1.500	15
4	0.25	3252	3.025	15

Freundlich and Langmuir (Ahalya *et al.*, 2006). Equations (3) and (4) correspond to these models.

$$q_e = K_F C_e^{1/n} \tag{3}$$

$$q_e = \frac{Q_{max} b C_e}{1 + b C_e} \tag{4}$$

where K_F (mg g^{-1} L$^{1/n}$mg$^{1-n/1}$) and n (dimensionless) are Freundlich constants, and Q_{max} (mg g^{-1}) and b (L mg^{-1}) are the maximum adsorption capacity and Langmuir constant. The data obtained were adjusted by a nonlinear estimation using the least squares method implemented in the Statistica 8.0 software.

Analytical methods

COD and nitrite were analyzed by a colorimetric method with a spectrophotometer (Spectroquant Pharo 300) following the procedure outlined in Standard Methods (APHA, 1985). The determination of the COD was based on the quantification of the oxygen equivalent in the organic matter content by the action of potassium dichromate in the presence of a catalytic solution of sulfuric acid and silver sulfate. This solution was introduced into a thermoreactor for 2 h, and finally, the absorbance was measured in the spectrophotometer at 620 nm, according to the norm NMX-AA-030-SCFI-2001 (SCFI, 2001).

For nitrate determination, a column containing cadmium filings lightly coated with metallic copper was used to reduce nitrate to nitrite. The nitrite produced was determined by diazotization with sulfanilamide and coupled with N-(1-naphthyl)-ethylenediamine to form a highly colored compound whose absorbance is measured in a spectrophotometer at 543 nm, according to norm NMX-AA-079-SCFI-2001 (SCFI, 2001). The VSS was performed according to procedures in Standard Methods. Before analysis, liquid samples were filtered with a 0.45 µm nylon membrane. The COD reported in the continuous reactor represented the sum of the COD corresponding to all the phenolic compounds in the study (phenol + *p*-cresol + *o*-cresol).

RESULTS AND DISCUSSION

Adsorption of phenolic compounds and nitrate on GAC

The removal of phenolic compounds (phenol, *p*-cresol, and *o*-cresol) in UASB reactors under denitrifying conditions with and without GAC occurred at different organic loads. In addition, the adsorption of these compounds on GAC was evaluated and modeled to identify the contribution of this process during the biodegradation. The adsorption isotherms of phenolic compounds and nitrate from aqueous solutions revealed that all compounds were adsorbed on GAC, following the Langmuir model (Figure 1). The maximum adsorption capacities were (mg g^{-1}): 164.6 for *o*-cresol, 134.5 for *p*-cresol, 110.7 for phenol, and 44.4 for nitrate. According to Li *et al.* (2021), the Langmuir model, which describes the
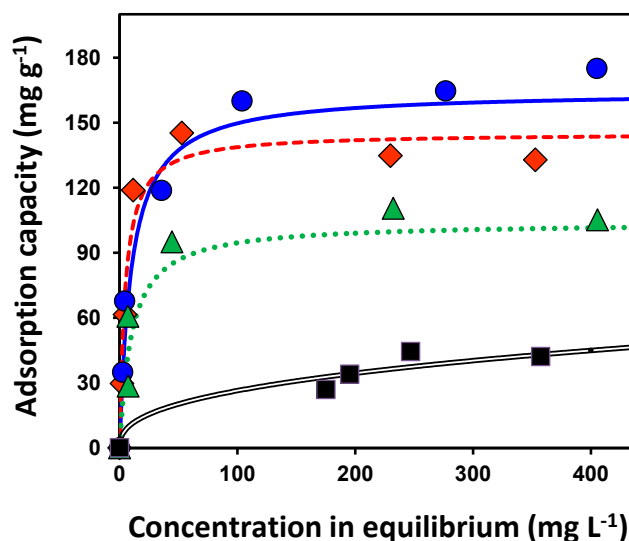

Figure 1. Adsorption isotherms of *o*-cresol (●), *p*-cresol (◆), phenol (▲), and nitrate (■) on GAC at pH 7.0. Langmuir model can be used to properly adjust the adsorption data of *o*-cresol (—), *p*-cresol (---), and phenol (•••). Freundlich model best describes the adsorption of nitrate (=).

Figura 1. Isotermas de adsorción de *o*-cresol (●), *p*-cresol (◆, fenol (▲) y nitrato (■) en CAG a pH 7.0. El modelo de Langmuir puede ser utilizado para ajustar los datos de adsorción de *o*-cresol (—), *p*-cresol (---) y fenol (•••). El modelo de Freundlich ajusta apropiadamente para la adsorción de nitrato (=).

adsorption of phenolic compounds, assumes that the surface of an adsorbent is uniform and that adsorption occurs on the outer surface of the adsorbent through monolayer adsorption. In the case of nitrate, the adsorption fits the Freundlich model since it does not asymptote as the concentrations of the compound increase.

The results indicate that cresols are adsorbed to a higher extent than phenol. According to Dąbrowsky *et al.* (2005), the Langmiur L class is the most observed class of adsorption of phenolic compounds, which indicates that the aromatic ring adsorbs parallel to the surface without significant competition between the adsorbate and the solvent to occupy the adsorption sites. Hamdaoui and Naffrechoux (2007) indicate that the main characteristics of phenols for adsorption are hydrophobicity, solubility, molecular weight, cross-sectional area, and acidity. A decrease in solubility is associated with an increase in adsorption capacity.

Additionally, it was documented that the adsorption of organic pollutants is proportional to the hydrophobicity between adsorbent and adsorbate (Fu *et al.*, 2021). The adsorption capacity of a given GAC for the different phenols is generally related to their solubility in water and the hydrophobic character of their substituents. Thus, *p*-cresol possesses very low water solubility and is typically adsorbed on the GAC, which is mainly different from the other phenols. However, *p*-cresol and *o*-cresol, which have a hydrophobic group, are also adsorbed more significantly than phenol, which has hydrophilic groups.

Another determining factor for the adsorption is the interaction between the phenolic compounds and the GAC

surface. Nouri *et al.* (2002) stated that the dispersion interactions between the aromatic rings of the phenolic compounds and those of the GAC surface, are the main forces involved in the adsorption process. Meanwhile, Al-Degs *et al.* (2000) indicate that the adsorption of phenol on GAC consists of the interaction between electron donors and acceptors, or it may even involve dispersion forces between the π electrons of the phenol and the π electrons of the graphene layers of the GAC. Table 2 shows the constants calculated from the Langmuir and Freundlich models. These values provide information about the behavior of the GAC surface used in the present study. For the Langmuir model, correlation coefficient values greater than 0.9 were obtained, indicating a proper fit of the isothermal model for all compounds. The model suggests that GAC does not have a homogeneous surface since *b* (constant of energy affinity) presents values below unity, from which it can be inferred that the adsorbent does not have a strong affinity for the solute molecules (Monroy, 2010). The Freundlich model provides information on the intensity of adsorption or surface heterogeneity, determined by the K_F and *n* constants. The K_F refers to the adsorption capacity of GAC, in which, at higher values, the affinity of the adsorbent for the adsorbate is greater. In this sense, the adsorption of *p*-cresol and *o*-cresol, with the highest K_F, indicates a greater adsorption affinity on GAC compared to nitrate, which had the lowest K_F.

Table 2. Isotherm parameters estimated from experimental data for the adsorption of pollutants on GAC at pH 7.0.
Tabla 2. Parámetros de isotermas estimados a partir de datos experimentales de adsorción de contaminantes en CAG a pH 7.0.

Pollutants	Langmuir			Freundlich		
	Q_{max}	b	r²	K_F	n	r²
p-cresol	144.0	0.213	0.900	59.9	6.43	0.753
o-cresol	177.6	0.101	0.976	48.3	4.35	0.945
Phenol	114.9	0.100	0.925	40.1	5.79	0.841
Nitrate	67.41	0.005	0.960	4.53	2.61	0.982

Units: Q_{max}: mg g^{-1}; b: L mg^{-1}; k: mg g^{-1} L$^{1/n}$mg$^{1-n/1}$; n: dimensionless.

Impact of GAC on the removal of phenolic compounds

The addition of GAC significantly improved the performance of the reactor, as evidenced by the high COD removal efficiencies compared to the reactor without GAC. The HRT for the two reactors was periodically adjusted from 2 to 0.25 d, with the accompanying adjustment in the carbon loading rates from 450 to 3250 mg C L^{-1}d^{-1}. Table 3 shows the four changes in loading rates and the removal efficiencies of phenolic compounds (measured as COD) and nitrate for each operating period studied.

The denitrifying consortium was able to simultaneously mineralize the phenolic compounds at the four loading rates tested, improving the removal efficiencies in both reactors with increasing loading rates (Figure 2). The addition of GAC improved the performance of the reactor, evidenced by the high COD and nitrate removal efficiencies compared to the reactor without GAC during the four operational periods, with statistical differences between means (Table 3). The efficiencies obtained in the reactor with GAC were 95 to 99 % for all periods, while the reactor without GAC had 89 % and 95 % removal efficiencies. In both reactors, the removal efficiencies increased gradually as the loading rate increased. The reactor without GAC showed a COD removal efficiency of 89.7 % in period 1, with lower efficiencies observed mainly during the first 20 days of operation due to an adaptation stage from biomass to phenolic compounds. Then, the efficiencies were ≥90 % during the same stage. Following this stage, the removal efficiencies were greater than 90 %, reaching the last stage of operation at the highest organic load-tested, an average of 95.5 %.

The removal of phenolic compounds under denitrifying conditions has been previously studied. For instance, the simultaneous oxidation of *p*-cresol or phenol with sulfide has been observed (Meza *et al.*, 2008; Liu *et al.*, 2016), as well as the oxidation of *p*-cresol with ammonium coupled with the reduction of nitrite (González *et al.*, 2012). Nonetheless, few studies have presented the oxidation of a mixture of phenolic compounds via denitrification, as presented in this study. The COD removal profiles of the reactor with GAC showed higher

Table 3. Performance of UASB reactors with and without GAC, removal efficiencies of COD (mixture of phenol, *p*-cresol, and *o*-cresol) and nitrate.
Tabla 3. Desempeño de reactores UASB con y sin CAG, eficiencias de eliminación de DQO (mezcla de fenol, *p*-cresol, y *o*-cresol) y nitrato.

Period (days)	COD removal efficiencies (%)			Nitrate removal efficiencies (%)		
	Influent loading rate (mg C L^{-1} d^{-1})	GAC + sludge	Sludge	Influent loading rate (mg N L^{-1} d^{-1})	GAC + Sludge	Sludge
1-50	450	95.8 ± 7.9[a]	89.7 ± 1.5[b]	140	79.3 ± 19.3[a]	64.8 ± 17.1[b]
51-60	1100	96.9 ± 0.1[a]	92.2 ± 1.4[b]	370	97.0 ± 3.0[a]	89.6 ± 6.6[a]
61-75	1600	97.7 ± 0.2[a]	93.5 ± 0.5[b]	590	93.7 ± 2.6[a]	90.4 ± 1.8[b]
76-90	3250	99.1 ± 0.7[a]	95.5 ± 0.1[b]	1140	98.0 ± 0.1[a]	96.9 ± 0.5[b]

GAC + sludge = UASB reactor with GAC; sludge = UASB reactor without GAC. COD, chemical oxygen demand. Different letters after each data indicate statistical differences (Tukey test, confidence level of 95 %). The test between means compares each reactor, GAC + Sludge vs. Sludge, for each independent period.
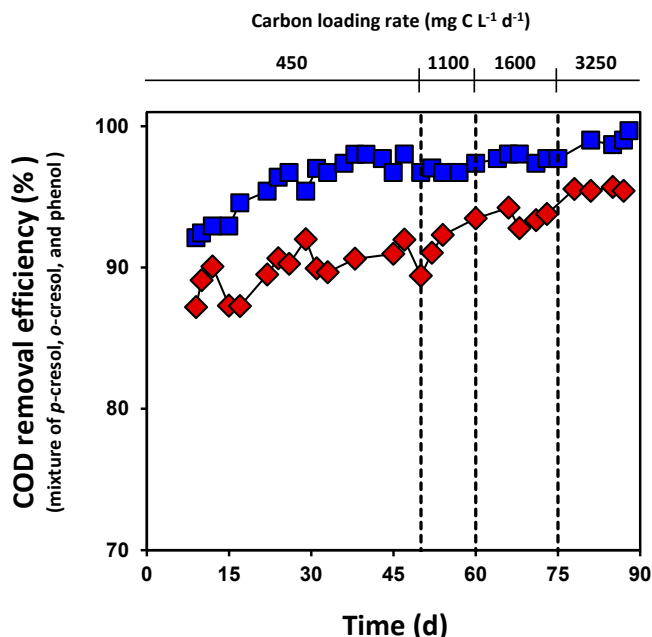
Figure 2. COD removal efficiencies in the UASB reactors with (■) and without (◆) GAC under different carbon loading rates. COD represents a mixture of *p*-cresol, *o*-cresol, and phenol.

Figura 2. Eficiencias de eliminación de DQO en los reactores UASB con (■) y sin (◆) CAG bajo diferentes cargas de carbono. DQO representa la mezcla de *p*-cresol, *o*-cresol y fenol.

stability throughout the entire operation period; conversely, the reactor without GAC showed slight decreases in the COD removal efficiencies in periods 2 and 3 after increasing the loading rate (Figure 2). The reactor with GAC showed slight increments, between 3.6 and 6.1 %, for the four operation periods above the reactor without GAC. The high removal efficiency of phenolic compounds in the reactor provided with GAC can be associated with the adsorption capacity of GAC, promoting a decrease in toxicity for microorganisms (Singh *et al*., 2016). Moreover, during the biodegradation of phenol, the GAC addition protects microorganisms from shock loads and improves tolerance through a protective effect due to rich pores (Li *et al*., 2023).

Impact of GAC on the removal of nitrate

Concerning nitrate, the reactors were similar to carbon compounds, achieving a better performance in the reactor with GAC througout all periods (Table 3 and Figure 3). During the first days of operation (1-30 days in period 1), nitrate removal was low in the reactor without GAC, requiring 30 days to decrease the concentration below 25 mg N L^{-1}d^{-1}; nonetheless, in the reactor with GAC required 15 days (Figure 3). The nitrate removal efficiencies in the reactor with GAC ranged from 79 to 98 %, whereas in the reactor without GAC were between 64 to 96 % (Table 3). The denitrifying condition can be confirmed by the nitrite measured in the effluent (Figure 3). This compound indicates partial denitrification, but complete denitrification is presumed to occur based on the high consumption of organic matter (i.e., phenolic compounds)
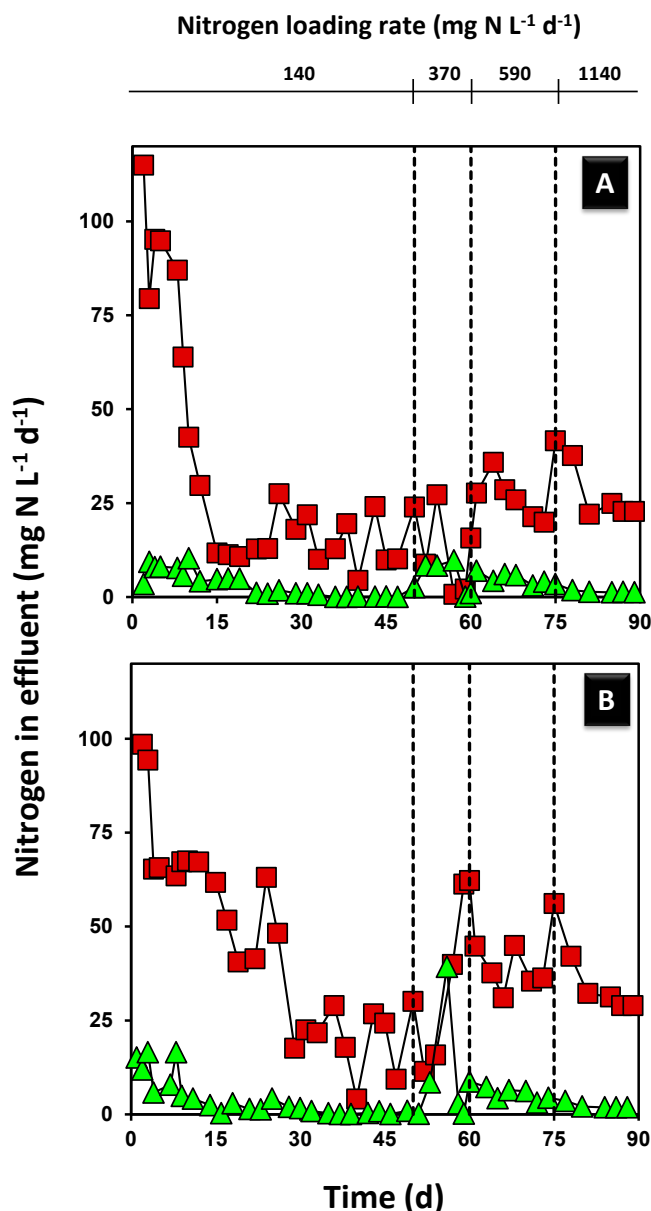

Figure 3. Nitrogen compounds profile in the effluent during all periods of operation using a mixture of *p*-cresol, *o*-cresol, and phenol, as an energy source by an anaerobic sludge. Panel A: reactor with GAC. Panel B: reactor without GAC. Symbols: Effluent N-NO$_3^-$ (■); Effluent N-NO$_2^-$ (▲).
Figura 3. Perfil de compuestos nitrogenados en el efluente durante todos los periodos de operación utilizando la mezcla de *p*-cresol, *o*-cresol y fenol, como fuente de energía por un lodo anaerobio. Panel A: reactor con CAG. Panel B: reactor sin CAG. Símbolos: Efluente N-NO$_3^-$ (■); Efluente N-NO$_2^-$ (▲).

observed in the two reactors. Considering the increment in the nitrate loading rate and the concentration in the effluent for each stage, it is suggested that microorganisms were adapted to the system, coinciding with high removal efficiencies of phenolics in both reactors, especially with GAC.

It is observed that with the increment in the removal of phenolic compounds, the removal of nitrate also increases, which is promoted by the electron transfer from the oxidation of the phenolic compounds, contributing to the reduction of nitrate during the denitrifying process. This performance is

observed to a high extent in the reactor with GAC compared to the reactor without GAC. It can be associated with the adsorption of phenolic compounds and nitrate, promoting their availability by microorganisms closer and sooner. The presence of nitrite in the effluent is minimal except at the beginning of the operation of the reactors, which may be due to the adaptation process of the biomass to phenolic compounds mentioned above. The reactor with GAC had a response up to 14 % (in period 1) higher than the reactor without GAC for nitrate removal. This response could be associated with carbon-based material's capacity to promote the biofilm formation with denitrifying bacteria on the core particles and promoting increment in the relative abundance of denitrification metabolic enzymes, except nitrate reducta-se and nitrogenase (Ge *et al*., 2018).

CONCLUSION
The results showed that it is possible to simultaneously bio-degrade phenol, *p*-cresol, and *o*-cresol in a UASB reactor un-der denitrifying conditions with removal percentages higher than 89.7 % at the different organic loads tested. In addition, it was observed that GAC increased the removal efficiency of all compounds, increasing from 89.7 % to 95.5 % obtained in the reactor without GAC, to 95.8 to 99.1 % in the reactor with GAC, as well as a possible the adaptation of the consortium to increases in organic load in the reactors. For the nitrate remo-val, the reactor with GAC achieved efficiencies from 79.3 % to 98.0 %; meanwhile, the control obtained 64.8 % to 96.9 %. The Langmuir model was the most appropriate to fit the experi-mental adsorption results of phenol, *p*-cresol, and *o*-cresol. The adsorption isotherms displayed the following order of adsorption capacity: *o*-cresol>*p*-cresol>phenol>nitrate. The results show the capacity of a denitrifying process to remove a mixture of phenolic compounds from industrial effluents, such as those discharged by the chemical and petrochemical industries.

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