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Research Article

# Evaluation of a combined activated carbon prefilter and biotrickling filter system treating variable ethanol and ethyl acetate gaseous emissions

The removal of a 1:1 by weight mixture of ethanol and ethyl acetate was studied in a gas phase biotrickling filter running under conditions that simulated industrial emissions from the flexographic sector, *i.e.* discontinuous loading (twelve hours per day and five days per week) and oscillating concentration of the inlet stream. Three sets of experimental conditions were tested in which empty-bed residence time varied from 60 to 25 s (inlet loads from 50 to 90 g C $m^{-3}$ $h^{-1}$). The biotrickling filter reached a maximum elimination capacity of 48.5 g C $m^{-3}$ $h^{-1}$ (removal efficiency = 68.9%) for an empty-bed residence time of 40 s. A decrease in the residence time from 40 to 25 s adversely affected the elimination capacity (40.3 g C $m^{-3}$ $h^{-1}$, removal efficiency = 46.6%). For the three tested residence times, outlet concentrations during pollutant feeding were above 100 mg C $m^{-3}$ (EU legal limit for flexographic facilities). Then an activated carbon prefilter was installed to buffer the fluctuating concentration, enabling a more stable operation. The desorbed pollutant from the activated carbon during non-feeding hours also served as an extra source of substrate, avoiding severe starvation. The use of the activated carbon prefilter with a volume 25 times lower than that of the bioreactor was shown to reach an average outlet emission concentration lower than 50 mg C $m^{-3}$ operating the biotrickling filter at an empty-bed residence time of 40 s, with a maximum elimination capacity of 59.6 g C $m^{-3}$ $h^{-1}$ (removal efficiency = 92.0%).

**Keywords:** Activated carbon / Biotrickling filter / Ethanol / Ethyl acetate

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## 1 Introduction

The abatement of volatile organic compounds (VOCs) from air emissions as a factor in the protection of the environment and public health has been emerging in European environmental policy in the last decade. Industries in which organic solvents are used are one of the main sources of VOCs, with emissions characterized by high flow rates and low VOC concentrations. In these cases, biotreatments are potential alternatives to conventional physicochemical processes, including absorption, adsorption, thermal oxidation and catalytic oxidation, owing to their lower operational costs and the lack of secondary pollutants production. Vapor-phase biotreatments have been classified as best available technologies (BATs) for the reduction of these pollutants from waste gas in the chemical sector [1].

Among biotreatments, the biotrickling filter (BTF) is an emergent technology that presents several additional advantages: potentially lower size, lower capital expenditure and higher removal rates than conventional biofilters. BTF uses a well-specified inert packing material and involves a liquid phase trickling through the bed. The biofilm is developed on the packing surface, and the liquid phase provides nutrients to the biofilm and allows for pH control, yielding a more stable operation than biofilters. These characteristics along with a larger air/liquid interfacial area can lead to higher removal rates than those obtained with conventional biofilters [2].

Most of the laboratory studies using BTFs have focused on the removal of even and continuous concentrations of pure

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compounds, with elimination capacities (ECs) reported up to 150 g $m^{-3} h^{-1}$ for easily biodegradable and hydrophilic VOCs [3] such as propionaldheyde and ethyl acetate. The fact that industrial emissions are usually discontinuous has increased the number of studies involving starving periods [4–7], showing that biomass starvation adversely affects biological activity, especially in long-term starvation conditions. Industrial emissions also present variable concentrations that can hinder the performance of field-scale BTFs [8], showing that bioreactors yield better under stationary conditions. Dampening the fluctuating concentrations has been a recent research objective, in order to enhance the reliability of BTFs to promote their application at real scale. In this context, several researchers have studied the use of activated carbon filters preceding a biological reactor to buffer the sudden variations in concentration, spikes and unstable loads of VOCs. It has been operated an activated carbon buffering bed coupled to a BTF [9]. The activated carbon prefilter was installed to ensure a relatively even load of pollutants for a 24 h per day emission in a flexographic facility. Concentration peaks were smoothed, facilitating a stable performance of the biological system and achieving a removal efficiency that complied with the VOC emission legal limitation. In addition, it has been used a trickle-bed air biofilter filled with coal particles and preceded by a coal particle buffer column to treat an emission produced during polyurethane and epoxy manufacture [10]. The coal buffer appeared to be very efficient at dampening the fluctuating ethyl acetate concentration produced during the cleaning periods, while during the production and break periods the ethyl acetate concentration slightly increased owing to the desorption process. The performance of the coupled system was improved in comparison with the stand-alone trickle-bed air biofilter. The efficiency of the buffering column was maintained until it was removed after 85 days of operation. It has also been reported that the use of activated carbon as a load equalization unit before a biofilter minimized toluene oscillations, improving the overall removal efficiency of the combined system [11]. Other authors have been evaluated the use of granular activated carbon as a passively operated load-equalization mechanism for conventional biofilters treating gas streams with dynamically varying pollutant loading, with acetone and toluene present as single-component contaminants and as a mixture [12]. In that study, the dynamic loading scenario investigated consisted of 8-h contaminant loading followed by 16-h non-loading each day during the whole week, operating at constant air flow rate. Results demonstrated that the non-buffered biofilter exhibited worse treatment performance over the entire period of study than the biofilter with the activated carbon buffering system. Recently, a two-bed adsorption unit involving a two-step cycle, *i.e.* adsorption and desorption, was tested to provide stable operation of a biofilter during dynamic toluene feeding [13]. The authors concluded that the use of the adsorption system attained the goal of treating fluctuating toluene loading with high removal efficiency compared with a stand-alone biofilter. After non-use periods, reacclimation performance was superior to the biofilter without the adsorption system, as pollutant desorption from the activated carbon functioned as a substrate source that kept the biofilter active during non-use periods.

The purpose of the present study was to establish the maximum dynamic loading that can be handled in a BTF treating waste gases typically found in flexographic printing facilities in order to accomplish legal regulations. The VOC emission limit imposed in the European Council Directive 1999/13/EC [14] in waste gases of these industries is 100 mg C $Nm^{-3}$. For this purpose, the performance of a stand-alone BTF and an integrated adsorption and BTF system to treat discontinuous and fluctuating emissions of ethanol and ethyl acetate was evaluated. In this context, the activated carbon buffering bed was conceived not only to mitigate the fluctuations in VOC concentration during the emission periods, but also to be desorbed in the shut-off periods in order to reduce the intensity of the starvation periods. The experimental plan was designed to investigate, in a first phase, the operation of a BTF under substrate starvation conditions associated with typical night and weekend closures. Then, in a second phase, the overall performance of the combined fixed-bed adsorption unit followed by the BTF was studied and compared with the stand-alone BTF.

## 2 Materials and methods

### 2.1 Experimental system

The experimental system, including the granular activated carbon prefilter (GACP) followed by the BTF, is shown in Fig. 1. The compressed, filtered and dry air was contaminated with the 1:1 by weight mixture of ethanol and ethyl acetate using a programmable syringe pump (New Era, infusion/withdraw NE 1000 model, USA) and introduced through the system. The air flow rate was adjusted by use of mass flow controllers (Bronkhorst Hi-Tec, the Netherlands). The GACP consisted of a 0.75-L vessel with 379 g of granular activated carbon (Norit RB3, OMYA Clariana S.L., Spain) crushed and sieved to 0.75–2.0 mm particle size. In the experiments

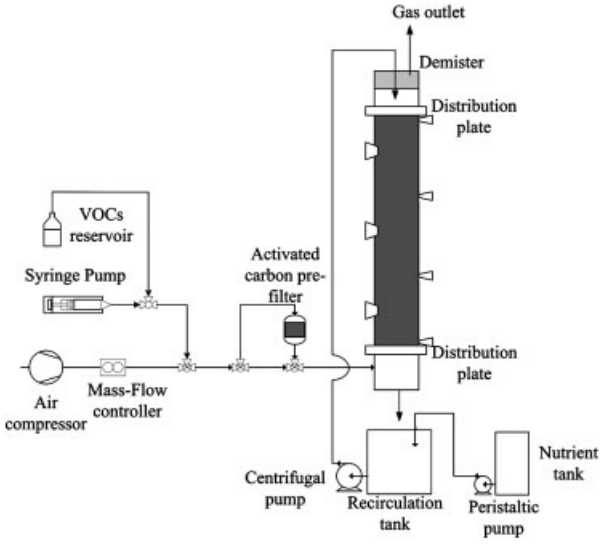


**Figure 1.** Schematic of the experimental system.

 

**Table 1.** Design parameters of the experiment

| | | | Working period (0–12 h) | | | Non working period (12–24 h) | | |
|---|---|---|---|---|---|---|---|---|
| | | | EBRT (s) | | IL ($g\,C\,m^{-3}\,h^{-1}$) | EBRT (s) | | IL ($g\,C\,m^{-3}\,h^{-1}$) |
| Stage | Days | Configuration | BTF | GACP | | BTF | GACP | |
| I | 0–129 | BTF | 60 | – | 50 | 175 | – | 0 |
| II | 130–144 | BTF | 40 | – | 70 | 175 | – | 0 |
| III | 145–165 | BTF | 25 | – | 90 | 175 | – | 0 |
| IV | 166–260 | GACP+BTF | 40 | 1.5 | 70 | 175 | 6.5 | 0 |
| V | 260–281 | GACP+BTF | 25 | 0.9 | 90 | 175 | 6.5 | 0 |

including the use of the GACP, the fixed-bed GACP received the contaminated air and the outlet was directly fed to the bottom of the BTF. The bioreactor was composed of three cylindrical modules of Plexiglas with a total bed length of 120 cm and an internal diameter of 14.4 cm. The reactor had two free spaces of 20 cm length at top and bottom to ensure good distribution of the fluids. The BTF was randomly filled with one inch of nominal diameter Flexiring$^{TM}$ polypropylene rings (Koch-Glitsh B.V.B.A., Belgium), with 92% initial porosity. The set-up of the bioreactor was completed with a 14-L recirculation tank. The recirculation solution, purged once per week, was fed counter-currently to the air flow using a centrifugal pump (flow rate of $3.5 \pm 1.5\,L\,min^{-1}$). A buffered nutrient solution containing potassium nitrate fertilizer ($3.01\,g\,N\,L^{-1}$), $Na_3PO_4 \cdot 12H_2O$ ($7.36\,g\,L^{-1}$), and Ca, Fe, Zn, Co, Mn, Ni and B at trace doses was used to incorporate all necessary macronutrients and micronutrients in the recirculation solution. The flow rate of the nutrient solution varied between 0.1 and $0.5\,L\,d^{-1}$ depending on the load applied to ensure $NO_3$-N concentrations in the recirculation tank above $10\,mg\,L^{-1}$. The BTF was seeded with an aerobic microbial culture pre-acclimated to a mixture of ethanol, ethyl acetate and methyl-ethyl ketone (MEK) obtained from a previous study [4].

## 2.2 Operational conditions

In order to simulate industrial emissions from a flexographic facility, a discontinuous loading was planned, in which overnight and weekend shutdown periods were considered; therefore the VOC mixture was fed intermittently to the system ($12\,h\,day^{-1}$, 5 days $week^{-1}$, *working period*). The fluctuations in the inlet concentration that can be found in situ related to daily rotations and product application in manufacturing were simulated by programming repetitive cycles of combined increasing and decreasing steps of variable duration of the syringe pump.

The biodegradation performance will be discussed using the terms defined below:

Inlet ($C_i$) and outlet ($C_o$) concentration of pollutant (mg C $m^{-3}$).
Empty bed residence time (s), $EBRT = V_f/Q$, where $Q$ = air flow rate ($m^3\,s^{-1}$), and $V_f$ = filter bed volume ($m^3$).
Removal efficiency (%), $RE = 100\,(1-C_o/C_i)$.
Inlet Load (g C $m^{-3}$ $h^{-1}$), $IL = 3.6\,C_i\,Q/V_f$.
Elimination capacity (g C $m^{-3}$ $h^{-1}$), $EC = 3.6\,Q\,(C_i-C_o)/V_f$.

The experiment was carried out in five stages over nine months. Operational parameters of the five stages of the study are summarized in Table 1. For each flow rate, a different inlet load (IL) was tested in order to operate under similar average inlet concentrations. In this study, IL means the average IL applied during working hours. For all the experiments, the air flow rate was lowered to $0.4\,m^3\,h^{-1}$ (EBRT of 175 s) during night and weekend closures, imitating industrial practice. Each set of operational conditions was maintained for a minimum of 14 days to ensure steady state conditions. In stages I-III, the BTF was operated without the GACP (stand-alone BTF configuration). Stage I was planned to evaluate the influence of a discontinuous water trickling regime on the removal efficiency (RE) of the BTF. Different cycles of 15 min of water trickling at a flow rate of $2\,L\,min^{-1}$ were applied (1, 2, 6, 12 and 24 cycles per day, respectively) at an IL of $50\,g\,C\,m^{-3}\,h^{-1}$ and an EBRT of 60 s. Discontinuous trickling of water was selected because its combination with short-term starvation periods has proven to be a successful strategy to avoid clogging in long-term operation of BTFs degrading a mixture of ethanol, ethyl acetate and MEK [4]. The results of this stage were used to establish the intermittent water trickling regime for the next stages. The transient and discontinuous pattern used in stage I is shown in Fig. 2 as an example. As can be observed, a fluctuating emission pattern of 2-h cycles with peak and base concentrations was obtained, including the typical short interruptions on the emissions. Stages II and III were run with a similar fluctuating emission pattern at progressively higher ILs, 70 and $90\,g\,C\,m^{-3}\,h^{-1}$, and lower EBRTs, 40 and 25 s, respectively, to evaluate the efficiency of the BTF working under more severe conditions. In stages IV and V, the combined system GACP and BTF was operated at similar ILs, EBRTs and emission pattern to those applied in stages II and III in order to evaluate the effect of the GACP in terms of elimination capacity (EC) and outlet concentration. The GACP was designed as a passively operated activated carbon buffering system, which means that the residence time (1–2 s) was fixed to promote not only VOC adsorption but also desorption at ambient temperature during non-working periods.

 

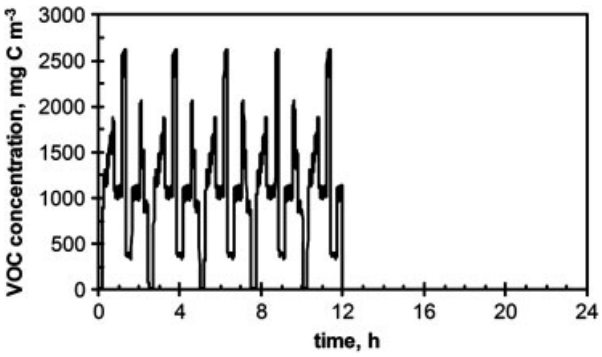


**Figure 2.** Concentration pattern of the inlet stream during a typical whole day in stage I (IL 50 g C $m^{-3}$ $h^{-1}$, EBRT 60 s).

### 2.3 Analytical methods

The concentration of VOC in the gas phase was measured with a total hydrocarbon analyzer (Nira Mercury 901 model, Spirax-Sarco, Spain) equipped with a flame ionization detector and calibrated with a propane-in-air mixture (Carburos Metálicos, Spain). Owing to the variable pattern of the inlet concentration fed to the system, the gas phase concentrations were monitored during the whole day, with a measurement frequency of 6 s.

Pressure drop was monitored daily when water was trickling through the bed by means of a digital manometer (KIMO, MP101 model, Spain). Conductivity, pH and temperature of the recirculation liquid were also analyzed daily. Suspended solids, soluble chemical oxygen demand (COD), and nitrate concentration in the recirculation solution were measured two or three times per week. The suspended solids were determined according to the Standard Methods for Examination of Water and Wastewater [15]. COD and nitrate concentrations were measured with Merck Spectroquant kits 14539 (COD) and 14773 (nitrate).

## 3 Results and discussion

### 3.1 Stage I: Influence of water trickling regime

In this stage the GACP was not used and the BTF was fed with an IL of 50 g C $m^{-3}$ $h^{-1}$ at an EBRT of 60 s during the VOC feeding hours (from 0 to 12 h). The trickling conditions were changed to evaluate the effect on the performance of the BTF in terms of RE. The experiment started by setting a trickling water cycle of 15 min per day increasing its frequency until 24 cycles per day. The RE vs. the number of trickling cycles is shown in Fig. 3. As can be observed, differences are not significant for the different number of trickling cycles used. In this stage, an average value of RE of 81.2% was achieved, with an average daily outlet concentration over 100 mg C $m^{-3}$ (163 mg C $m^{-3}$). The intermediate value, six cycles of trickling water per day, was selected for the next stages.

### 3.2 Stages II to III: Biotrickling filter unit

In these stages, the BTF unit was operated under higher ILs and lower EBRTs than stage I. Results obtained in these stages were used as control values to compare the performance with the integrated system composed of the GACP followed by the BTF. The BTF performance was evaluated in terms of average IL, EC, RE and outlet concentration. Results are summarized in Table 2. The monitoring of the concentration of the VOC inlet and the outlet streams is presented for typical days during stages II and III in Fig. 4. As can be seen, during the working period the outlet concentrations were almost always above the EU legal limit imposed on flexographic facilities (100 mg C $m^{-3}$), the effluent response followed the same cyclic pattern as the inlet stream, and the maximum and minimum outlet concentrations were obtained when maximum and minimum inlet concentrations were applied. Re-acclimation period was apparently non-existent after the non-working interval, observing a cyclic behavior with a better performance during the first four to six hours of operation. Outlet emissions at the starting of the VOC feeding (0–2 h) reached the minimum values of the feeding period (0–12 h), showing that bacteria metabolism was immediately reactivated after organic substrate re-feeding. No significant difference was observed after starting of the VOC feeding after night or weekend closures.

During the non-feeding period (12–24 h), the soluble COD of the recirculation water trickling was used as an extra source of organic substrate for biofilm maintenance. Some increases in the outlet concentration during non-feeding period observed during stage III (e.g. slight step after hour 18, Fig. 4B) could be attributed to desorption process from the liquid phase to the gas phase.

The average outlet concentrations during the VOC feeding hours (0–12 h) were 240.6 mg C $m^{-3}$ (average RE of 68.9%) and 323.1 mg C $m^{-3}$ (average RE of 46.6%) during stages II and III, respectively. Under these operational conditions the biological reactor was not able to degrade sufficiently the fluctuating inlet

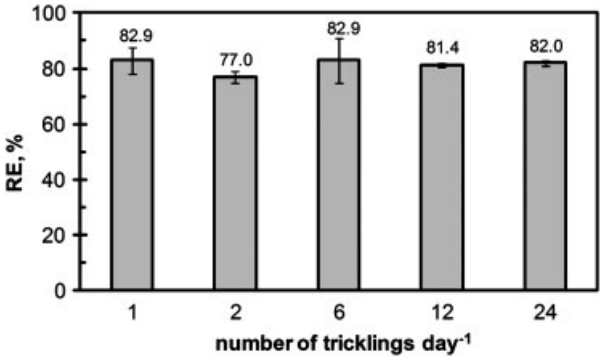


**Figure 3.** RE vs. number of cycles of water trickling per day applied in stage I.

**Table 2.** Operational and average performance parameters in the stand-alone BTF configuration obtained during working periods (0–12 h)

| Stage | IL (g C $m^{-3}$ $h^{-1}$) | EC (g C $m^{-3}$ $h^{-1}$) | RE (%) | Outlet concentration $C_O$ (mg C $m^{-3}$) |
|---|---|---|---|---|
| II | 70.5 ± 3.1 | 48.5 ± 2.8 | 68.9 ± 3.5 | 240.6 ± 30.0 |
| III | 86.6 ± 1.9 | 40.3 ± 5.8 | 46.6 ± 6.4 | 323.1 ± 37.7 |

 

concentrations, with a maximum EC of 48.5 g C $m^{-3}$ $h^{-1}$ achieved at stage II (EBRT of 40 s, IL of 70.5 g C $m^{-3}$ $h^{-1}$). The decrease in the EBRT to 25 s applied in stage III (IL of 86.6 g C $m^{-3}$ $h^{-1}$) caused a decrease in the EC, with a value of 40.3 g C $m^{-3}$ $h^{-1}$. These data are lower than those obtained in our previous study [4] regarding the removal of a mixture of ethanol, ethyl acetate and MEK in a BTF in which the same intermittent loading pattern was applied, but without fluctuating concentrations in the inlet stream: we found a maximum EC of 96 g C $m^{-3}$ $h^{-1}$ for a total inlet load of 141 g C $m^{-3}$ $h^{-1}$ operating at an EBRT of 16 s. It has previously been found a maximum EC of 114 g C $m^{-3}$ $h^{-1}$ at an IL of 149 g C $m^{-3}$ $h^{-1}$ operating a BTF at 57 s of EBRT and under continuous ethanol feeding [16]. It has also been reported an EC of 277 g C $m^{-3}$ $h^{-1}$ at an IL of 295 g C $m^{-3}$ $h^{-1}$ degrading ethyl acetate in a trickle-bed air biofilter working at 60 s of EBRT [17]. Comparing these results with the data obtained in the present study, it can be seen how the fluctuating concentrations adversely affected the removal capacity of the BTF.

### 3.3 Stages IV to V: Activated carbon prefilter and biotrickling filter system

As the BTF was unable to control the outlet concentration below 100 mg C $m^{-3}$, it was decided to install a GACP preceding the BTF in order to evaluate the capacity of the activated carbon to buffer the inlet peaks and its effect on bioreactor performance. It has previously been reported that there is no need to regenerate the activated carbon other than by using the driving force naturally occurring and associated with the decrease in the influent contaminant concentration imposed on the waste stream during non-use periods [18]. In this context, the GACP was designed to promote not only adsorption during the VOC feeding hours but also desorption during non-working periods. The typical emission days of each stage (IV to V) can be seen in Fig. 5; system inlet patterns of stages IV (Fig. 5A) and V (Fig 5B) are similar to those shown for stages II (Fig. 4A) and III (Fig. 4B), respectively. The use of an activated carbon prefilter dampened the fluctuating concentration of the inlet stream during VOC feeding periods (0–12 h), and its desorption during non-use periods (12–24 h) served as an extra source of pollutants for the bioreactor, yielding more even feeding than the BTF working alone. Comparing the results with the previous stages (see Fig. 4), the use of the GACP dramatically improved the bioreactor response at an EBRT of 40 s (IL of 65.8 g C $m^{-3}$ $h^{-1}$, stage IV), although the EU legal limits were not met when an EBRT of 25 s was used (IL of 91.1 g C $m^{-3}$ $h^{-1}$, stage V). The results of the coupled system (GACP+BTF) in terms of average IL, EC and outlet concentration are shown in Table 3. Experimental data of the GACP inlet and BTF inlet during the two periods (VOC feeding from 0–12 h and non-VOC feeding from 12–24 h) are also included, as well as the EC and outlet concentration. During the 12-h period of non-use, a 10 g C $m^{-3}$ $h^{-1}$ of the VOC loading was released from the GACP to

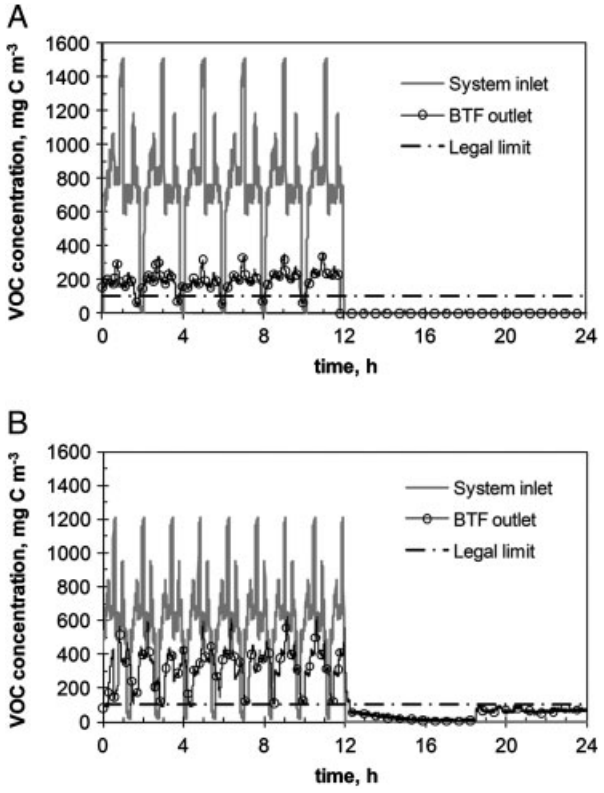


**Figure 4.** Monitoring data of typical whole days during the stand-alone BTF configuration. (**A**) stage II and (**B**) stage III.

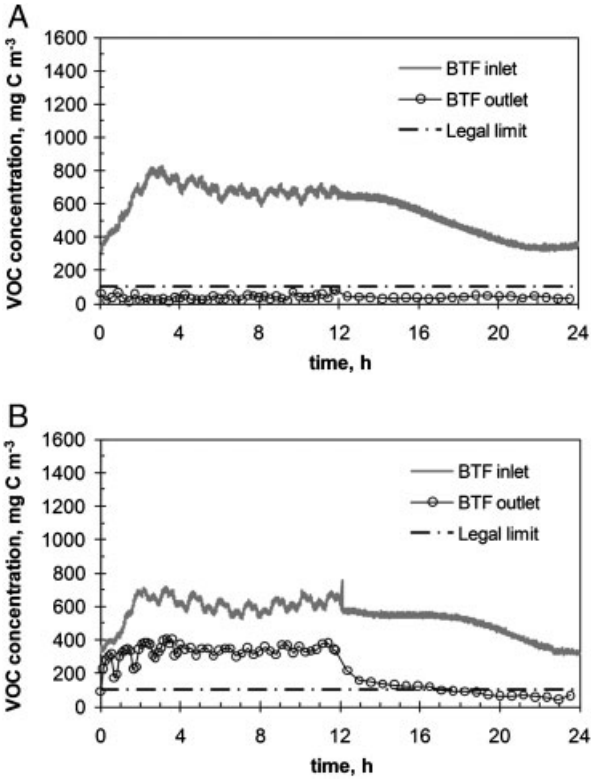


**Figure 5.** Monitoring data of typical whole days during the GACP +BTF configuration. (**A**) stage IV and (**B**) stage V.

 

**Table 3.** Operational and average performance parameters in the GACP+BTF configuration

| Stage | GACP | BTF | | |
|---|---|---|---|---|
| | IL ($g\,C\,m^{-3}\,h^{-1}$) | IL ($g\,C\,m^{-3}\,h^{-1}$) | EC ($g\,C\,m^{-3}\,h^{-1}$) | Outlet concentration $C_O$ ($mg\,C\,m^{-3}$) |
| IV | | | | |
| Working period (0–12 h) | 65.8±0.8 | 54.6±11.5 | 50.0±12.0 | 50.3±40.1 |
| Non-working period (12–24 h) | 0 | 10.2±1.4 | 9.6±1.4 | 28.1±24.3 |
| V | | | | |
| Working period (0–12 h) | 91.1±4.5 | 82.0±3.0 | 40.8±3.0 | 288.0±95.3 |
| Non-working period (12–24 h) | 0 | 10.1±0.7 | 8.1±0.7 | 103.3±40.0 |

the biological reactor. As can be deduced from the data, the GACP is working under stable operation with reversible adsorption/desorption cycles. The sum of the inlet VOC applied to the bioreactor during feeding and non-feeding hours matched the total inlet VOC applied to the GACP during the working period, retaining the buffer capacity of the activated carbon when VOC emission re-started. Results from stage IV indicated that the average outlet concentrations were as low as 50.3 and 28.1 $mg\,C\,m^{-3}$ during working and non-working periods, respectively, with a total EC of 59.6 $g\,C\,m^{-3}\,h^{-1}$ (23% increase compared with EC without GACP, stage II), showing that the configuration of GACP+BTF could reach the EU legal limits, treating a discontinuous emission with transient concentrations working at an EBRT in the BTF of 40 s. At an EBRT in the BTF of 25 s (stage V), a total EC of 48.9 $g\,C\,m^{-3}\,h^{-1}$ was obtained (21% increase compared with EC without using GACP, stage III). In this case, improvement was not enough to meet the legal regulation of VOC emission, showing that the selected EBRT in the biological reactor was too low to ensure an adequate biological degradation.

### 3.4 General remarks

The recirculation solution was totally purged once per week. The soluble COD values measured in the wastewater purge, represented less than 8% of the inlet load fed to the system during the week, with values varying between 400 and 3500 $mg\,L^{-1}$ depending on the VOC loading. The average values are plotted in Fig. 6 for stages II to V. As can be seen, the use of an activated carbon prefilter decreased the organic load in the purge, facilitating the management of the water stream. During the whole experiment the conductivity of the recirculation solution was kept under 5 $mS\,cm^{-1}$, with pH values between 7.7 and 8.5, and temperature values between 18 and 25°C. The average concentration of suspended solids of the recirculation solution was 1102 $mg\,L^{-1}$ (standard deviation of 829 $mg\,L^{-1}$). No clogging problems occurred during the whole experiment, keeping pressure drop values lower than 280 $Pa\,m^{-1}$, during stages I to III with the stand-alone BTF, and under 360 $Pa\,m^{-1}$ during stages IV to V with the integrated GACP+BTF configuration.

## 4 Conclusions

The removal in a BTF of an emission of a 1:1 w/w mixture of ethanol and ethyl acetate simulating a focus coming from a flexographic facility was studied for nine months. The BTF showed a stable performance under oscillating concentrations and intermittent loadings with short-term starvation periods related to night and weekend closures that typically occurred in industrial facilities. The regime of discontinuous recirculation of water with 15 min of water trickling cycles (from 1 to 24 cycles per day) did not show significant differences in the RE of the BTF, with an average value of 81.2% operating at an IL of 50 $g\,C\,m^{-3}\,h^{-1}$ and 60 s of EBRT (stage I). Keeping constant the inlet concentration pattern and decreasing the EBRT to values of 40 and 25 s (stages II and III) caused a decrease in the performance of the BTF, with REs of 68.9 and 46.6% respectively. Transient emissions failed to meet the EU legal regulations (average hourly outlet concentrations $<100\,mg\,C\,m^{-3}$) for the flexographic sector for the three EBRTs tested.

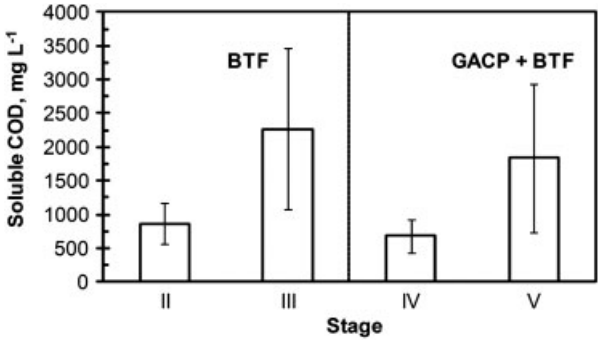


**Figure 6.** Comparison of the soluble COD values of wastewater purge for the stand-alone BTF and the GACP+BTF configurations.

A GACP installed prior to the BTF was shown capable to buffer the oscillating concentrations of the inlet stream. The decrease of the air flow rate during non-VOC feeding periods (typical situation at industrial sites) was sufficient to promote full VOC desorption of the GACP. The GACP allowed operation of the biological reactor under relatively stable inlet concentration during VOC feeding hours, while the pollutant desorption during non-feeding periods served as an extra source of substrate to the BTF. A GACP with a volume 25 times lower than the BTF was shown to improve the performance of the biological system sufficiently to reach an average daily outlet emission concentration lower than 50 $mg\,C\,m^{-3}$ when the BTF was operated at 40 s of EBRT (IL of 70 $g\,C\,m^{-3}\,h^{-1}$).

 

For an EBRT of 25 s (IL of 90 g C $m^{-3}$ $h^{-1}$) the installation of the GACP increased the EC by 20%, but it was not able to reach the legal limit. In addition, the installation of the GACP also produced a decrease in the soluble COD values of the weekly wastewater purge.

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### Conflict of interest

The authors have declared no conflict of interest.

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