17th International Conference on Environmental Science and Technology

Athens, Greece, 1 to 4 September 2021

Sustainable treatment of air pollutants by moving bed biofilm reactor (MBBR) coupled with algae photobioreactor (APBR)

Pahunang R. R.[1], Zarra T. [2*], Oliva G.[2], Senatore V. [2], Belgiorno V. [2], Ballesteros Jr. F. C. [3], Naddeo V. [2]

[1] Environmental Engineering Program, National Graduate School of Engineering, University of the Philippines, Diliman, Quezon City, Philippines

[2] Sanitary Environmental Engineering Division (SEED), Department of Civil Engineering, University of Salerno, via Giovanni Paolo II, Fisciano, SA, Italy

[3] Department of Chemical Engineering, University of the Philippines, Diliman, Quezon City, 1101 Philippines

*corresponding author:
e-mail: tzarra@unisa.it

Abstract The presence of high concentrations of VOCs in the atmosphere can lead to negative consequences for humans and the environment. The treatment of these compounds is thus necessary before their release into the atmosphere. In the study, an advanced moving bed biofilm reactor (MBBR) coupled with an algae photobioreactor (APBR) is presented with the aim of investigating its application for the sustainable biodegradation of toluene (C_7H_8). The results highlight that the MBBR alone shows a high removal efficiency (RE), ranging from 98.37 ±0.79% to 99.84 ±0.14%. Whiile, setting the Algal PhotoBioreactor (APBR) as second treatment, the biodegradation of toluene increases up to 99.91%. The research depicts the potential of the investigated system to biodegrade volatile organic compounds (VOCs), leading to a healthy environment.

Keywords: odour, plastic carrier, greenhouse gases, toluene biodegradation, volatile organic compounds.

1. Introduction

Volatile organic compounds (VOCs) belong to the atmospheric pollutants that can be harmful to humans and the environment if present in significant concentrations (Giuliani et al., 2012). Among them, toluene (C_7H_8) is hazardous to humans and the environment because of its neurotoxicity in nature and plays a major role in forming a petrochemical smog (Oliva et al., 2019; Senatore et al., 2020). The control of the C_7H_8 compound is therefore necessary before its release to the atmosphere(Zarra et al., 2012).

The treatment of VOCs includes physical-chemical and biological treatments. Physical-chemical treatment technologies entail the consumption of a large amount of chemicals and energy (Chen et al., 2010; Pahunang et al., 2021). While biological treatments represent an efficient and low-cost alternative. Bacteria growth on the plastic carrier to promote biological degradation of VOCs has recently been explored, showing promising performance in VOCs abatement (Lebrero et al., 2021). The advantage of using carriers in the reactor is linked to the enhancement of oxygen transport in addition to the accumulation of biomass (Daigger & Boltz, 2017). Microalgae cultivation in photobioreactor (PBR) has also been investigated, demonstrating its effectiveness for the treatment of VOCs in combination with the consortium of bacteria, exploiting their symbiotic metabolisms (Anbalagan et al., 2017; Oliva et al., 2019; Senatore et al., 2021). Since algae need carbon dioxide to grow, the CO_2 produced by highly concentrated waste gas treatment with a moving bed biofilm reactor (MBBR) can be a perfect way to cultivate algae biomass.

The research present and discusses the investigation of an integrated, innovative MBBR-PBR system with the aim to explore its removal efficiency (RE) and elimination capacity (EC) for the treatment of gas stream with a concentration of toluene up to 600 mg/m^3. The study also highlights how the algae cultivation represents an opportunity to promote the sustainable treatment of toluene.

2. Materials and methods

2.1. Microorganisms preparation and inoculum

The *Chlorella vulgaris* (*C. Vulgaris* CCAP 211/11B) acquired from the Culture Collection of Algae and Protozoa (CCAP), Dunberg, Scottland were pre-inoculated with bold basal medium (BBM). On the other hand, bacterial sludge (0.5 L) from the wastewater treatment plant located in Battipaglia (Salerno, Italy) was centrifuged at 9000 rpm in 10 mins and resuspended in a synthetic wastewater medium. The C. vulgaris (2 L) and sludge were suspended in the reactor with synthetic wastewater with the following composition (mg/L): $C_6H_{12}O_6$ (200), C_{12}H22O11 (200), Proteine (68.33), (NH_4)2SO_4 (66.73), NH_4Cl (10.01), KH_2PO_4 (4.43), K_2HPO_4 (9), $MgSO_4H_2O$ (21), $MnSO_4H_2O$ (2.68), $NaHCO_3$ (30), CaCl.6H_2O (19.74), and $FeCl_3$.6H_2O (0.14).

2.2. Experimental design and operating condition

The schematic layout of the experiment is shown in Figure 1. The MBBR was made of glass with an internal size of 50 cm height and 15 cm in diameter, while the PBR was made of plexiglass with an internal diameter of 18 cm and 100 cm height. The working volume in the MBBR and PBR are 6.50 L and 26 L, respectively. The algal culture was mixed continuously using a magnetic mixer (IKA® C-MAG HS 10). Pure liquid toluene was feed in the system through a syringe pump (model No. 300 from New Era Pump Systems, Inc.) and was diluted with ambient air via an air compressor (COMPACT 120, fiac Air Compressor) where the airflow rate was controlled using a flowmeter (Platon NG, Roxspur Measurement & Control). Three gas sampling ports (GSP) were integrated into the airline to constantly measure and monitor the concentration of toluene, as well as the concentration of the CO_2. The MBBR was filled (30% filling factor) with plastic carriers (Amitec, Italy) and the PBR was also illuminated by two white-light-emitting diode (LEDs). The specific operating conditions of the parameters at different stages are described in Table 1.

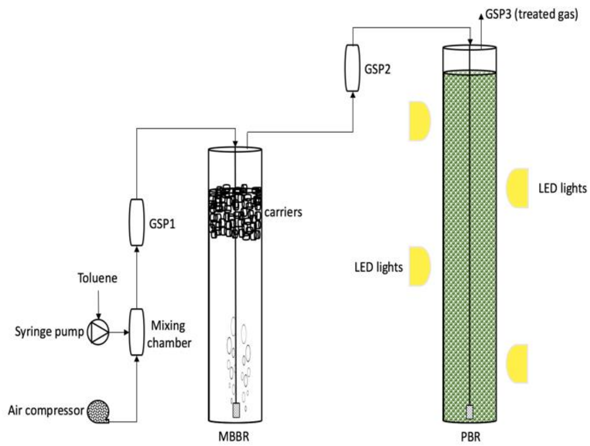

Figure 1. Schematic layout of the experimental set-up

Table 1. Operating conditions of the parameters at different stages

Parameters	Stages		
	I	II	III
Air flowrate (L/min)	1	1	0.50
Light intensity (Lux)		6457.88	
Light and dark ratio (h)		12:12	
Mixing in PBR (rpm)		300	
Duration of toluene feeding (h)	24	8	24

The airflow rate and the duration of toluene feeding were the parameters varied to enhance the attachment of biomass on the carriers, hence increasing the toluene biodegradation efficiency.

2.3. Analytical methods

The culture temperature, pH, and DOerewere measured using a multi-parameter probe (HI 9829 from HANNA Instruments). The concentration of toluene was measured using a GC-PID (Gas chromatography -Photo Ionization Detector, Ion Science). The concentration of CO2 was measured using a GC-TCD (TRACE™ 1300 Gas Chromatography, Thermo Fisher). The total biomass concentration suspended in the system was measured in terms of total suspended solids (TSS) according to the Standard Method for the Examination of Water and Wastewater (Vermi et al., 2021).

3. Results and discussion

The biodegradation of C_7H_8 in the experimental monitoring period, using the integrated system of MBBR and APBR, are highlighted in Figure 2 and their main numerical results in Table 2. The removal efficiency (RE) of MBBR ranges from 98.37 % to 99.84 % while the whole system (WS) showed a slight increase in RE ranges from 99.65 % to 99.91 % as it can be seen in standard deviation and frequency in the entire course of the inlet load ($Load_{in}$). These results indicate that the PBR enhanced the biodegradation of C_7H_8 as microalgae are also capable of oxidizing organic contaminants by bio-absorption (Sample et al., 1999). The RE in stage III is more stable compared to stage I and stage II. This can be attributed to the higher empty bed residence time (EBRT) of the C_7H_8 in the system.

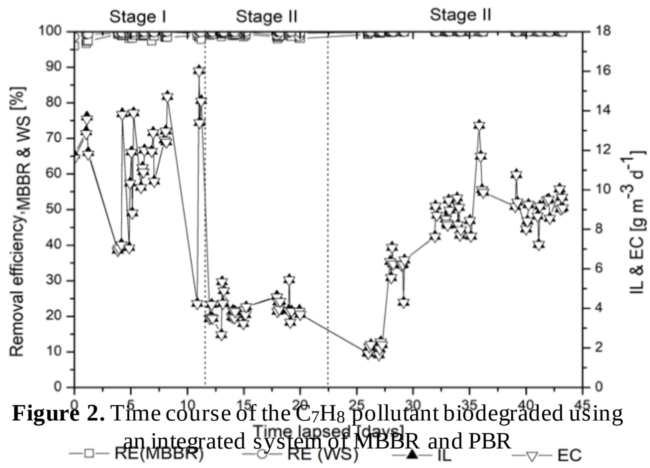

Figure 2. Time course of the C_7H_8 pollutant biodegraded using an integrated system of MBBR and PBR

Table 2. Results of the responses in biodegrading C_7H_8 at different stages

Responses	Stages		
	I	II	III
RE_{EMBR} (%)	98.37	98.87	99.83
RE_{WS} (%)	99.65	99.74	99.91
IL (g $m^{-3}d^{-1}$)	11.35	3.96	7.49
EC (g $m^{-3}d^{-1}$)	11.32	3.95	7.49

The $Load_{in}$ ranged from 3.96 g m^{-3} d^{-1} to 11.35 g m^{-3} d^{-1}, while the EC from 3.95 g m^{-3} d^{-1} to 11.35 g m^{-3} in the entire course of the biodegradation of C_7H_8. Stage I of the experiment showed a higher $Load_{in}$ compared to stage II and stage III, as air flowrate and the number of hours that the C_7H_8 was feed into the system were higher in stage I. Though, the EC in stage I and stage II were also higher, the $Load_{in}$ and EC almost converge in stage III with an average EC of 7.49 g m^{-3} d^{-1} as C_7H_8 was almost biodegraded in the system as shown in its RE_{WS} in Table 2.

4. Conclusion

The high RE of the system confirms that biodegradation using MBBR presents an efficient solution for the treatment of waste gas contaminated with VOCs. The PBR, as an integrated treatment, enhanced the RE besides reducing CO2 emissions. The RE of the integrated MBBR and PBR increased from 99.65% to 99.90%, with $Load_{in}$ from 3.95 g m^{-3} d^{-1} to 11.315 g m^{-3} d^{-1}.
Although the system, MBBR, and PBR integration, showed a high potential of biodegrading C_7H_8, it is important to consider that biological oxidation is also potential to produce a more dangerous by-product especially that the system used wastewater as a nutrient for bacteria and medium for algal cultivation. Thus, it is highly recommended to determine the biological species in the MBBR reactor to know the oxidation pathways of the C_7H_8 and determine the possible production of more dangerous gas contaminants. Nevertheless, the algal cultivated in the system was homogenous and can be valorized. Moreover, using wastewater as a medium in support of nutrients to bacteria and serve as a medium for algal biomass cultivation makes the system more sustainable.

References

Anbalagan, A., Toledo-Cervantes, A., Posadas, E., Rojo, E. M., Lebrero, R., González-Sánchez, A., Nehrenheim, E. and Muñoz, R. (2017), Continuous photosynthetic abatement of CO2 and volatile organic compounds from exhaust gas coupled to wastewater treatment: Evaluation of tubular algal-bacterial photobioreactor, *Journal of CO2 Utilization*, **21**, 353–359.

Chen, J. M., Zhu, R. Y., Yang, W. B. and Zhang, L. L. (2010), Treatment of a BTo-X-contaminated gas stream with a biotrickling filter inoculated with microbes bound to a wheat bran/red wood powder/diatomaceous earth carrier, *Bioresource Technology*, **101**(21), 8067–8073.

Daigger, G. T. and Boltz, J. P. (2017), Oxygen Transfer in Moving Bed Biofilm Reactor and Integrated Fixed Film Activated Sludge Processes, *Water Environment Research*, **90**(7), 615–622.

Giuliani, S., Zarra, T., Nicolas, J., Naddeo, V., Belgiorno, V. and Romain, A.C. (2012), An alternative approach of the e-nose training phase in odour impact assessment, *Chem. Eng. Trans.* **30**, 139–144.

Lebrero, R., Rodr, E., Juan, C. De, Norden, G. and Rosenbom, K. (2021), Comparative Performance Evaluation of Commercial Packing Materials for Malodorants Abatement in Biofiltration, *Applied Sciences*, **11**(7), 2966.

Oliva, G., Ángeles, R., Rodríguez, E., Turiel, S., Naddeo, V., Zarra, T., Belgiorno, V., Muñoz, R. and Lebrero, R. (2019), Comparative evaluation of a biotrickling filter and a tubular photobioreactor for the continuous abatement of toluene, *Journal of Hazardous Materials*, **380**, 120860.

Pahunang, R. R., Buonerba, A., Senatore, V., Oliva, G., Ouda, M., Zarra, T., Muñoz, R., Puig, S., Ballesteros, F. C., Li, C.-W., Hasan, S. W., Belgiorno, V. and Naddeo, V. (2021), Advances in technological control of greenhouse gas emissions from wastewater in the context of circular economy, *Science of The Total Environment*, **792**, 148479. https://doi.org/10.1016/j.scitotenv.2021.148479

Sample, K. T., Cain, R. B. and Schmidt, S. (1999), Biodegradation of aromatic compounds by microalgae, *FEMS Microbiology Letters*, **170**(2), 291–300.

Senatore, V, Zarra, T., Oliva, G., Belgiorno, V. and Naddeo, V. (2020), Volatile organic compounds (VOCs) control by combining bio-scrubber and ozone pretreatment, *Global NEST Journal*, **22**(2), 143–146.

Senatore, V, Buonerba, A., Zarra, T., Oliva, G., Belgiorno, V., Boguniewicz-Zablocka, J. and Naddeo, V. (2021), Innovative Membrane Photobioreactor for Sustainable CO2 Capture and Utilization, *Chemosphere*, **273**, 129682

Zarra, T., Giuliani, S., Naddeo, V. and Belgiorno, V. (2012), Optimization of field inspection method for odour impact assessment, *Chemical Engineering Transactions*, **23**, 93-98.