OTAER biotechnology: a new pathway of reaching the Zero Net Carbon in Odours Treatment

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Abstract Emissions of odours into ambient air represent a serious problem and cause for conflict, due to the effects they cause on the population and on the exposed environment. Their treatment is therefore a priority. The approach currently pursued by the conventional odour treatment technologies is focused on reducing the odour concentration and/or on the degradation of the odorous substances into non-odorous ones. The operation of these systems, however, determines the production and emission of greenhouse gases (GHGs) and therefore climate change issues. The research presents and discusses the identification and development of an advanced, integrated, and sustainable odour treatment technology, biological based, called OTAER system. The aim is to promote a new integrated treatment system that combines the reduction of odours with the control and recovery of GHGs for the purpose of subsequent valorization in energy terms. The technology fits into the principles dictated by the New Green Deal and in compliance with the guidelines of the SDGs (objectives n.7 and n.13). The research presents the results of an intense experimental validation activity of the OTAER system on different odorous compounds. The percentages of abatement and the production of algal-biomass are reported and discussed. The proposed system highlights the importance of developing and implementing integrated biotechnologies, aiming to applying circular economy approaches, in order to guarantees the total environmental protection, including the reduction of climate change emissions.

Keywords: air pollution; biotechnology; environmental sustainability; Hydrogen sulfide; odor treatment wastewater treatment plant.

1. Introduction

Odour pollution is a serious environmental problem that has attracted worldwide attention (Zarra et al., 2009). The intensification of human activities and industrialization have led to a steady increase in odour emissions into the environment in recent years (Naddeo et al., 2013). Presence of unpleasant odour in ambient air, constitutes cause of environmental discomfort as it compromises the usability of environments, residential and non-residential places, with a consequent deterioration in the quality of life (Zarra et al., 2010; Piccardo et al., 2021). It is therefore necessary to control these emissions to avoid negative effects on the environment and the health of the exposed population (Zarra et al., 2012; Belgiorno, 2017). The approach currently pursued by the conventional odour treatment technologies is focused on reducing the odour concentration and/or on the degradation of the odorous substances into non-odorous ones. The operation of these systems, however, determines the production and emission of greenhouse gases (GHGs) and therefore climate change issues. Climate change has been a well-known problem and its magnitude is set to grow exponentially in the absence of immediate solutions (Rama et al., 2022; Zarra et al., 2016). Carbon capture and utilization (CCU) technologies using microalge, in this sense, emerged as sustainable and effective platform to reduce GHGs emissions in ambient air and produce valuable biomass (Oliva, Galang, et al., 2023). Microalgae cultivation usually is realized in photo-bioreactors (PBRs). However, their use is still characterized by drawbacks that need to be investigated (Ugwu et al., 2008) in order to increase their efficiency and reliability (Assunção & Malcata, 2020).

The research presents and discusses the development and validation of an advanced, integrated air emission treatment system, composed of two different bioreactors, working in synergy to carry out the oxidation of the treated odour compounds and the capture of CO_2 released from the biological degradation process, with cultivation of algal biomass. Compared to previous studies (Oliva et al., 2023; Pahunang, et al. 2023) conducted on the abatement of organic chemical compounds, this study focuses on the oxidation of inorganic odour compounds. H_2S was investigated as target inorganic unpleasant odorous compound. The removal efficiency and biomass production were evaluated and discussed under different operating conditions.

2. Materials and methods

2.1 OTAER system

The innovative OTAER (Odor Treatment and Algal Energy Recovery) biotechnology combines a Moving Bed Bio Bioreactor (MBBR), for the biological treatment of odour compounds, and an algal PhotoBioReactor (PBR), for the biofixation of the CO_2 produced and its conversion into algal biomass. In a circular economy perspective, the biomass produced can be used for the production of biofuels or other value-added products (Singh & Dhar, 2019). The system set-up was realized with two reactors (Figure 1): a MBBR (R_1), inoculated with active sludge, and an algal PBR (R_2) inoculated with microalgae. The MBBR reactor has an internal height of 50 cm and a diameter of 15 cm, while the PBR reactor has an internal diameter of 18 cm and height of 100 cm. The working volume in the MBBR and PBR were 6,5 L and 26 L, respectively. The algal culture in PBR was continuously stirred at 300 rpm.

The inlet gaseous stream, wet by a bubbler, passes into the mixing chamber where a chemical reaction between iron sulfide (FeS), water and HCl (diluted to 3,5%) generates H_2S. The hydrogen sulfide was fed into the system by means of an automatic syringe pump and the inlet concentration was varied according to the amount of FeS and HCl dilution in input. The airflow rate was controlled using a flowmeter. Three gas sampling ports were integrated into the airline for the measurement of H_2S and CO_2 concentrations inlet and outlet concentrations. The MBBR was filled (30% filling factor) with plastic carrier. The PBR was illuminated by four white light-emitting diodes (LEDs) with a 12/12 h cycle of alternance of light and dark. The operating conditions were varied in order to assess the performances of the systems in the different investigated stages.

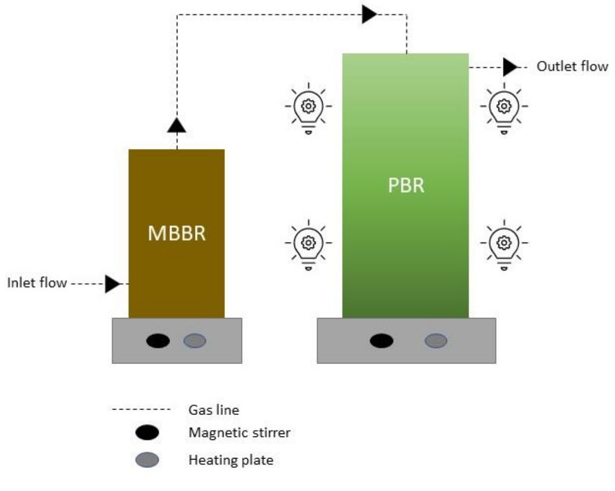

Figure 1. OTAER system

2.2 Experimental plan and program

The analyses were conducted by introducing a stream containing hydrogen sulphide into the system as a target parameter. The system feeding time for each internship was 6 hours/day. Four different operating conditions (stages) were performed during the whole investigation program. The I stage, with a biweekly duration, was based on an inlet concentration of H_2S of 100 ppm. Dairy effluent of 100 ml/d for R_1 and 500 ml/d for R_2 was used as additional nutrient for both reactors. Stage II, varies from the previous stage in terms of mineral renewal; a daily turnover of 250 ml/d for R_1 and 500 ml/d for R_2 were used. All other parameters and conditions remain unchanged. While in Stage III, the concentration of H_2S were increased at 300 ppm; the daily amount of nutrients fed into the system was 250 ml/d for R_1 and 500 ml/d for R_2. All other parameters and conditions remain unchanged. The last stage, stage IV, reduces the concentration of H_2S at 200 ppm, with an amount of nutrients fed daily into the R_1 and R_2 reactors, equal to 250 ml/d and 1000 ml/d respectively. Table 1 resume the operating conditions of the system.

Table 1. Operating conditions

Stages	QG [m3/min]	H2S Cin [ppm]	Tipo di WW	MR [ml/d] R1	MR [ml/d] R2	Light Intensity [LUX]
I	0,001	100	DWW	100	500	8258
II	0,001	100	BBW/DWW	250	500	8561
III	0,001	300	BBW/DWW	250	500	8155
IV	0,002	200	DWW	250	1000	8372

The inoculum of MBBR was realized by sampling activated sludge from a real wastewater treatment plant. The reactor was filled to one third of its volume with plastic support materials, Carrier, Kaldnes Ring, in order to promote greater adhesion of the bacterial biofilm. Air with hydrogen sulphide was fed into the MBBR through metal diffusers at the bottom. Chlorella vulgaris was used as microalgae species, acquired from the Culture Collection of Algae and Protozoa and pre-incubated with the modified Bold's Basal Medium (mBBM) prepared according to previous studies (Senatore et al., 2022).

2.3 Analytical analysis

Evaluation parameters include abatement efficiency and biomass production. Removal efficiency was evaluated in terms of hydrogen sulphide and carbon dioxide reduction. More specifically, the removal efficiency was evaluated by the following equation:

$$RE\ [\%] = \frac{C_{IN} - C_{OUT}}{C_{IN}}$$

where:

- C_{in} = inlet concentration of the investigated parameter;
- C_{out} = outlet concentration of the investigated parameter.

RE was assessed for the single R_1 reactor, the single R_2 reactor and the integration of the two, $R_1 + R_2$.

Specifically, for hydrogen sulphide the following parameters and equations were used:

Inlet Load (IL): which represents the hourly inlet concentration of the compound used in the system:

$$IL_{TOT}\left[\frac{g}{m^3\ h}\right]=\frac{C_{IN}*Q_G}{V_{TS}}*\frac{60}{1000}$$

Elimination Capacity (EC): represents the amount of compounds removed from the system with respect to volume and in a given period:

$$EC_{TOT}\left[\frac{g}{m^3\ h}\right]=\frac{Q_G*(C_{IN}-C_{OUT,2})}{V_{TS}}*\frac{60}{1000}$$

Removal Efficiency (RE): represents the removal as a percentage of the target compound used by the system.

While for the carbon dioxide (CO_2) parameters, the following equation was used:

$$CO_{2\ P,R}\left[\frac{g}{m^3\ h}\right]=\left[\left(\frac{CO_{2\ out}}{P\ _{out}}\right)-\left(\frac{CO_{2\ in}}{P\ _{in}}\right)\right]*\frac{Q_G}{V_R}*60$$

Volumetric biomass production was assessed by the following equation:

$$P\left[\frac{g}{l\ d}\right]=\frac{X_t-X_{t0}}{t-t_0}$$

where:

- X_t represents the solids concentration at time t [g/l].
- X_{t0} represents the solids concentration at time t_0 [g/l].

3. Results and discussions

Figure 2 shows CO_2 trends in Inlet, in $Outlet_1$ and in $Outlet_2$.

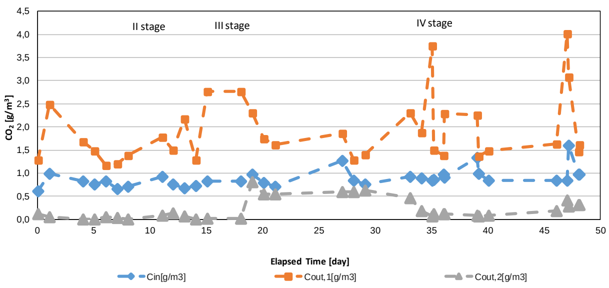

Figure 2. CO_2 trends in Inlet, $Outlet_1$ and $Outlet_2$

Results shows how the concentration of CO_2 increases in reactor R_1, where the degradation process of the target odorous compound investigated takes place, and then decreases almost totally in reactor R_2, where biofixation takes place due to the presence of algae. The CO_2 concentration at the outlet of the algal photobioreactor is lower than the concentration measured at the inlet, indicating that high biofixation occurs by the algal mass in the R_2 reactor.

The good functioning of the OTAER system is summarily represented also by the growth of the total suspended solids and chlorophyll values (Figure 3).

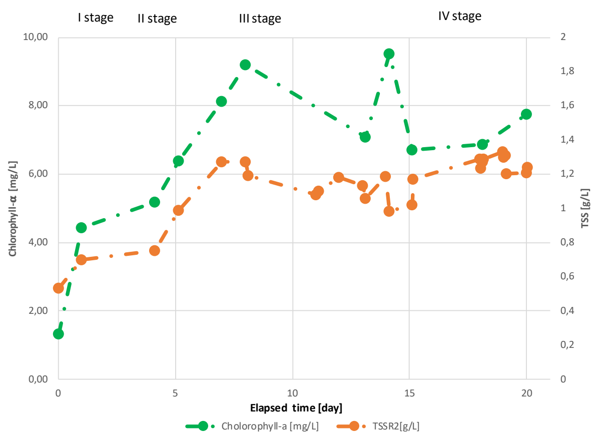

Figure 3. Chlorophyll and total suspended solids trends in the R_2 reactor.

The trends are summarily always upward, barring an event that characterised a momentary decrease in both evaluation parameters, due to external conditions that were quickly restored. These parameters are direct indicators of algal biomass growth and support the proper functioning of the integrated biosystem.

Figure 4 highlights the CO_2 and H_2S removal efficiencies of the integrated system and the algal biomass production in R_2 throughout the experimental period.

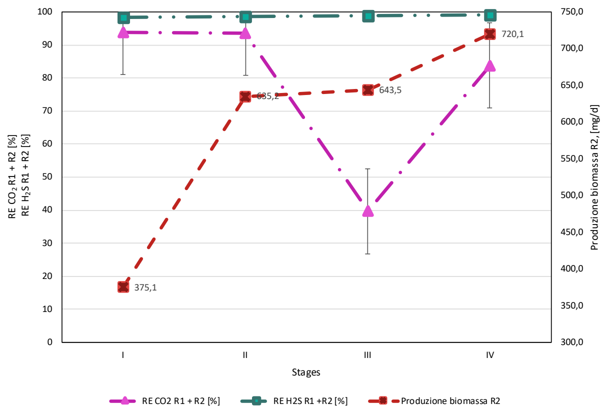

Figure 4 CO_2 and H_2S removal efficiencies in the R_1 + R_2 system and algal biomass production in R_2.

Results shows the achievement of high removal efficiencies of hydrogen sulphide in all the investigated stages. Specifically, in stage I, 98.34% was achieved, in stage II, 98.63%, in stage III, 98.83% and in stage IV, 99.18%. Similarly good carbon dioxide removal was recorded throughout the system (eg. at Stage I, 93.90%, Stage II 93.67%).

As well as the algal biomass inside the photobioreactor has recorded a constant increase, during the various stages, confirming the functioning of the proposed system.

4. Conclusions

The development of innovative biotechnologies for the treatment of odors and the consequent climate-altering gases deriving from the process represents, in a circular economy perspective, an opportunity to reduce the pressures and the consequent environmental impacts produced by industrial and environmental sanitary engineering plants.

The research presented an innovative integrated system which, through an integrated system of the microbial type, for the degradation of the odorous compounds, and of the algal type, for the biofixation of the process CO_2 produced, aims to return an odorless gas free of GHG in the atmosphere, with a view to reducing climate change. The biomass obtainable from the system also allows it to be valorised in energy terms, thus further increasing the sustainability of the proposed system.

The results obtained can be considered very satisfactory, as the abatement yields were higher than 99% for the investigated target odorous compound (H_2S) and higher than 94% for the biofixation of CO_2.

The overall results allow us to confirm a high application potential of the investigated system, which allows the abatement of the gaseous compounds analyzed in a circular economy perspective, creating added value.

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