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Selection of odour removal technologies in wastewater treatment plants: A guideline based on Life Cycle Assessment

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ABSTRACT

This paper aims at analysing the environmental benefits and impacts associated with the treatment of malodorous emissions from wastewater treatment plants (WWTPs). The life cycle assessment (LCA) methodology was applied to two biological treatments, namely biofilter (BF) and biotrickling filter (BTF), two physical/chemical alternatives, namely activated carbon tower (AC) and chemical scrubber (CS), and a hybrid combination of BTF + AC. The assessment provided consistent guidelines for technology selection, not only based on removal efficiencies, but also on the environmental impact associated with the treatment of emissions. The results showed that biological alternatives entailed the lowest impacts. On the contrary, the use of chemicals led to the highest impacts for CS. Energy use was the main contributor to the impact related to BF and BTF, whereas the production of glass fibre used as infrastructure material played an important role in BTF impact. Production of NaClO entailed the highest burdens among the chemicals used in CS, representing ~90% of the impact associated to chemicals. The frequent replacement of packing material in AC was responsible for the highest environmental impacts, granular activated carbon (GAC) production and its final disposal representing more than 50% of the impact in most categories. Finally, the assessment of BTF + AC showed that the hybrid technology is less recommendable than BF and BTF, but friendlier to the environment than physical/chemical treatments.

1. Introduction

Wastewater treatment plants (WWTPs) are considered important sources of gaseous emissions, including green house gases (GHG) and odorants (Shaw and Koh, 2013). The malodorous emissions associated with treatment processes are considered one of the major concerns of exposed population living in surrounding areas of WWTPs.

In this context, the concentration of malodours in the air is often monitored and controlled with the aim of complying with odour regulations while keeping a respectable public image of the emission sources.

Odour abatement technologies have been widely investigated as cost-efficient and reliable alternatives for the mitigation of odour nuisance (Revah and Morgan-Sagastume, 2005; Schlegelmilch et al., 2005). These technologies are commonly classified into physical/chemical and biological techniques. Physical/chemical technologies have been broadly implemented as a consequence of their rapid start-up, low empty bed residence time (EBRT) and consolidated know-how and experience in design and operation. These techniques are often based on the transfer of odorants from the gas emission to either a solid (adsorption) or liquid (absorption) phase. These pollutants can be further transformed into by-products according to their reactivity with the chemicals used. However, in the last decades biological systems have been increasingly used due to their ability to efficiently treat malodorous emissions at lower operating costs (Schlegelmilch et al., 2005). The main advantages of bioprocesses compared to their physical/chemical counterparts derive from their low generation of secondary wastes and low demand of resources, such as chemicals or

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adsorbent media. On the other hand, biological processes often require larger EBRTs (2–120 s *vs.* 1–5 s) and associated footprint than physical/chemical alternatives at similar odour removal efficiencies.

Technologies for odour treatment have been widely reviewed in the literature in order to establish their optimal range of application and performance for the removal of volatile organic compounds (VOCs) and volatile inorganic compounds (VICs). Nowadays, there are enough experimental evidences regarding the capability of biofilters and biotrickling filters to achieve significantly high removal efficiencies of air pollutants at both trace levels (Lebrero et al., 2014, 2012) and industrial concentrations (Balasubramanian et al., 2012; Omri et al., 2013). Estrada et al. (2012) demonstrated that biological techniques were the most cost-efficient alternatives with lower sensitivity to design parameters and lower operating costs than physical/chemical treatments at typical odour concentrations emitted in WWTPs. In terms of sustainability, Estrada et al. (2011) assessed the performance of different physical/chemical and biological odour abatement technologies based on the IChemE Metrics methodology (IChemE, 2002). The analysis focused on major environmental indicators such as resource use, waste production and emission impacts as well as process economics and social impact. This preliminary study showed as compared to physical/chemical technologies, biological treatments presented lower demand of energy, material and chemicals and limited production of hazardous wastes. These systems were the most favourable option despite the required high initial investment costs when analysing investment costs and operational costs over 20 years.

Although the aforementioned reports offered valuable information for the selection of the most suitable technology for the treatment of malodorous emissions, the IChemE Metrics methodology is only focused on the target process and does not consider a holistic approach for the assessment. For instance, despite water consumption or material use being considered as environmental indicators, the impact of their production processes is out of the scope of the IChemE Metrics analysis. Nevertheless, the origin and management of the components/consumables of the system under study could also be major contributors to the environmental impact. Previous research papers showed how a complete environmental evaluation helps to select the most adequate treatment technology, considering not only removal efficiencies but also potential environmental impacts (Alfonsín et al., 2013; Hospido et al., 2012).

Life cycle assessment (LCA) methodology is a quantitative procedure to assess the environmental burdens associated with products, processes and services, which is commonly used for environmental impact evaluation (Baumann and Tillman, 2004; ISO, 2006b). Although this methodology has been widely and satisfactorily applied to technologies dealing with wastewater treatment (Hospido et al., 2004; Rodriguez-Garcia et al., 2011), there is, to the best of our knowledge, only one application of LCA to the abatement of gaseous emissions, focused on lab-scale biofilters (Alfonsín et al., 2013).

This study aimed at enriching the guidelines for the selection of the best technological alternative for the treatment of malodorous emissions under an environmental perspective. In this context, a comprehensive LCA was performed in order to determine the overall environmental impacts of five full-scale odour abatement technologies in a WWTP scenario: biofilter (BF), biotrickling filter (BTF), activated carbon filter (AC), chemical scrubber (CS) and a hybrid technology consisting of a BTF coupled with AC (BTF + AC). The results obtained for each technology were compared to the environmental impact derived from the direct discharge of the malodorous emission without treatment, named non treatment scenario (NT).

2. Materials and methods

The ISO 14040 (ISO, 2006a) standard determines four basic stages for LCA studies: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and finally, interpretation of results (Baumann and Tillman, 2004). Goal and scope definition constitutes the first phase of an LCA and aims at defining the boundaries of the study and the quality of data used. A functional unit (FU), which represents the function of the system under study, must be also established in this phase. Then, LCI is performed, which involves data collection and interpretation of inputs and outputs. The allocation procedure is also conducted during the LCI phase, which consists on distributing input and output flows among the products of the process. LCIA represents the third phase and its purpose is to convert LCI data into potential impacts associated to products and processes. LCIA includes two mandatory steps (i.e. classification and characterization) and other optional elements, such as normalization and weighting. Finally, the interpretation of the results allows identifying the hot spots of the process as well as recommending options to reduce the environmental burdens.

2.1. *Goal and scope definition*

This study was conducted to evaluate the environmental impacts associated with the performance of five of the most commonly implemented odour abatement technologies in WWTPs. The functional unit chosen in this study was 1 m^3 of treated air, which is consistent with the approach used in a previous study evaluating lab-scale gas-phase bioreactors (Alfonsín et al., 2013).

2.2. *System boundaries*

The system boundaries determine the units and elements of the process included in the analysis (ISO, 2006a). The assessment here conducted considered the incoming polluted emissions, which are directly discharged to the atmosphere in the NT scenario, the output treated emission, material used in the infrastructure, consumables (e.g. packing material), potable or secondary plant effluent water, energy use, chemicals and transportation and final disposal of all wastes. Water input is required in all systems except in AC and potable water instead of WWTP secondary effluent water is used in CS. The secondary effluent water of the WWTP is considered a product related to wastewater treatment and no impact is attributed when used for irrigating the packing material of the biofilter or the biotrickling filter. The leachate collected in each technology (except in AC) was not considered in the analysis since it is returned to the WWTP headworks with a negligible flow in comparison with the net flow treated in the WWTP. The transportation from the manufacturing industry to the odour treatment facility of consumables like packing materials and chemicals was included.

2.3. *Description of odour treatment technologies*

Five odour abatement technologies were assessed: two biological (BF and BTF), two physical/chemical (CS and AC) and a hybrid technology (BTF + AC). The model malodorous stream of 50000 m^3h^{-1}, representing a typical emission from WWTPs, included 30 different VOCs (Zarra et al., 2008), methanethiol (1.97 mg m^{-3}) and hydrogen sulphide (20.9 mg m^{-3}) (Table 1). The odorants were classified into groups of high, medium and low hydrophobicity, which largely determine their removal efficiencies in the technologies evaluated (Estrada et al., 2011). A typical release of CO_2 of 0.75 g C–CO_2 (g-$C_{oxidized}$)$^{-1}$ due to the microbial oxidation of odorants and a biomass yield of 0.25 g C-biomass (g-$C_{oxidized}$)$^{-1}$ were considered. Water was supplied to the BF, BTF and CS in order