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Research review paper

A sensitivity analysis of process design parameters, commodity prices and robustness on the economics of odour abatement technologies

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ABSTRACT

The sensitivity of the economics of the five most commonly applied odour abatement technologies (biofiltration, biotrickling filtration, activated carbon adsorption, chemical scrubbing and a hybrid technology consisting of a biotrickling filter coupled with carbon adsorption) towards design parameters and commodity prices was evaluated. Besides, the influence of the geographical location on the Net Present Value calculated for a 20 years lifespan (NPV20) of each technology and its robustness towards typical process fluctuations and operational upsets were also assessed. This comparative analysis showed that biological techniques present lower operating costs (up to 6 times) and lower sensitivity than their physical/chemical counterparts, with the packing material being the key parameter affecting their operating costs (40–50% of the total operating costs). The use of recycled or partially treated water (e.g. secondary effluent in wastewater treatment plants) offers an opportunity to significantly reduce costs in biological techniques. Physical/chemical technologies present a high sensitivity towards H_2S concentration, which is an important drawback due to the fluctuating nature of malodorous emissions. The geographical analysis evidenced high NPV20 variations around the world for all the technologies evaluated, but despite the differences in wage and price levels, biofiltration and biotrickling filtration are always the most cost-efficient alternatives (NPV20). When, in an economical evaluation, the robustness is as relevant as the overall costs (NPV20), the hybrid technology would move up next to BTF as the most preferred technologies.

Contents

Abbreviations: AC, activated carbon adsorption; BF, biofiltration; BTF, biotrickling filtration; BTF + AC, hybrid technology consisting of a biotrickling filter coupled with an activated carbon adsorption unit; CS, chemical scrubbing; EBRT, empty bed residence time; NPV20, Net Present Value calculated for a 20 years lifespan; WWTP, wastewater treatment plant.

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1. Introduction

The expansion and encroachment of urban residential areas on potential malodor sources such as wastewater treatment plants (WWTP), chemical and food industries or solid waste treatment facilities has resulted in an increasing number of public complaints (Lebrero et al. , 2011). This, together with the fact that a frequent exposure to malodors involves a direct threat to human welfare and health, has lead to tighter environmental regulations (Sucker et al., 2008). For instance, densely populated countries like Germany or the Netherlands have recently approved stricter odour regulations, which will be likely adapted by other countries in a near future (Nicolay, 2006). Thus, odour management has become a major environmental and economical issue, not only due to the enforcement of odour-related regulations, but also because most companies are increasingly aware of their public image.

Odour treatment technologies can be classified as physical/chemical (incinerators chemical scrubbers, adsorption systems, etc.) and biological (biofilters, biotrickling filters, bioscrubbers and activated sludge diffusion reactors) (Lebrero et al., 2011; Revah and Morgan-Sagastume, 2005). Despite these techniques are not different from those generally used in industrial off-gas treatment, their selection criteria have not been fully validated in the field of odour treatment (often characterized by high volumetric flow rates of complex pollutant mixtures at trace level concentrations) (Delhoménie and Heitz, 2005). A recent sustainability analysis carried out by the authors quantified the environmental and social impacts, and the net present value (NPV20), of the most commonly used odour abatement technologies, confirming the more sustainable performance of biological technologies and the key relevance of the operating costs in the overall process economics (Estrada et al., 2011). However, this study also revealed the high uncertainty in the evaluation of the operating costs due to their high dependence on process design parameters, and wage and commodity prices (which are time and location dependant). Unfortunately, there is a lack of systematic studies assessing the influence of these variables on process economics, which today still constitutes the main selection criterion despite the recent increased attention on sustainability.

A detailed sensitivity analysis should also include the quantification of the operational risks for each technology by quantifying process robustness. In this context, detractors of biological treatment technologies have pointed out process robustness as their main drawback, although recent studies suggest that state-of-the-art biotechnologies can be as robust as their physical/chemical counterparts (Kraakman, 2003; Lebrero et al., 2010). However, the number of case studies systematically assessing the robustness of biological odour treatment techniques is scarce.

This study was thus designed to evaluate the influence of the cost of the energy, chemicals, water, packing material and labour along with reactor design parameters such as the size (=empty bed residence time, EBRT), packing lifespan, pressure drop and H_2S concentration on the process economics (operating costs and NPV20) of the five most commonly applied odour abatement technologies: biotrickling filtration, biofiltration, activated carbon adsorption, chemical scrubbing and a hybrid technology (biotrickling filtration coupled with activated carbon adsorption). Additionally, a comparative analysis of the net present value (NPV20) of the five technologies evaluated as a function of their geographical location was carried out for thirteen representative cities in the world. Finally, a semi-quantitative analysis of the robustness of each technology towards typical process fluctuations and operational upsets was undertaken. This sensitivity analysis, together with the previous paper by the authors (Estrada et al., 2011), provides up-to-date guidelines for odour abatement technology selection.

2. Materials and methods

2.1. Model malodorous emission

An emission of 50,000 $m^3 h^{-1}$ (293 K, 1 bar, 40% relative humidity) with a composition based upon the characterization of the odour pollution from a WWTP located at Stuttgart University (Germany) was selected as model malodorous emission (Zarra et al., 2008). Methyl mercaptan (2 mg m^{-3}) and hydrogen sulphide (21 mg m^{-3}) were also included in the above mentioned emission (Barbosa et al., 2002; Estrada et al., 2011). This emission was used as a reference in the sensitivity and geographical analysis here developed and all the cases mentioned.

2.2. Odour abatement technologies

The technologies here evaluated rank among the most commonly applied methods in the field of odour treatment: biofiltration, biotrickling filtration, chemical scrubbing, activated carbon adsorption and a hybrid technology composed of biotrickling filtration backed up by activated carbon filtration. These technologies, and therefore this sensitivity analysis, can be applied in different industries: WWTPs, food industries, livestock farms and municipal solid waste treatment facilities. The reference design parameters for each of the evaluated technologies are described below (Estrada et al., 2011) for abatement efficiencies higher than 99% for H_2S and higher 95% for odour:

2.2.1. Biofilter (BF)

A system packed with a mixture of compost (75%) and perlite (25%), a pressure drop (ΔP) of 1000 Pa m^{-1} (including the pressure drop in the humidifier) and a lifespan of 2 years with a packing material cost of 72 € m^{-3} was used as model biofilter (Lebrero et al., 2010). The unit operated at an EBRT of 60 s with a packed bed height of 1 m (Burgess et al., 2001; Harreveld, 2007; Revah and Morgan-Sagastume, 2005). A cost of 42 € m^{-3} (non-hazardous waste) and 30 € m^{-3} $year^{-1}$ were considered for disposal, and transport and handling, respectively, of the packing material.

2.2.2. Biotrickling filter (BTF)

A 2-stage biotrickling filter of 2 m packed bed height (1 m per stage) with a total EBRT of 15 s was here selected. The first stage operates at low pH (around 2), optimal for acidophilic H_2S oxidizing bacteria and the second one operates at a more neutral pH eliminating the rest of odorants. The system was packed with inert plastic packing with a lifespan of 10 years, a cost of 1200 € m^{-3} and a total ΔP of 500 Pa (Dorado et al., 2009). The relatively high cost of the packing material is based on previous experience in full-scale applications to guarantee the lifespan and removal efficiencies higher than 99% for H_2S and 95% for odour. Liquid nozzles were used for the dispersion of the recycling aqueous medium at 7.2 L $m^{-3}_{reactor}$ min^{-1} (0.9 m h^{-1}). The renewal of the aqueous medium was calculated based on the empirical design criterion of 2.5 L/g H_2S removed (Estrada et al., 2011). A cost of 120 € m^{-3} or 320