



# Pilot-scale biofiltration at a materials recovery facility: The impact on bioaerosol control



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## ABSTRACT

This study investigated the performance of four pilot-scale biofilters for the removal of bioaerosols from waste airstreams in a materials recovery facility (MRF) based in Leeds, UK. A six-stage Andersen sampler was used to measure the concentrations of four groups of bioaerosols (*Aspergillus fumigatus*, total fungi, total mesophilic bacteria and Gram negative bacteria) in the airstream before and after passing through the biofilters over a period of 11 months. The biofilters achieved average removal efficiency (RE) of 70% (35 to 97%) for *A. fumigatus*, 71% (35 to 94%) for total fungi, 68% (47 to 86%) for total mesophilic bacteria and 50% (-4 to 85%) for Gram negative bacteria, provided that the inlet concentration was high ( $10^3$ – $10^5$  cfu m<sup>-3</sup>), which is the case for most waste treatment facilities. The performance was highly variable at low inlet concentration with some cases showing an increase in outlet concentrations, suggesting that biofilters had the potential to be net emitters of bioaerosols. The gas phase residence time did not appear to have any statistically significant impact on bioaerosol removal efficiency. Particle size distribution varied between the inlet and outlet air, with the outlet having a greater proportion of smaller sized particles that represent a greater human health risk as they can penetrate deep into the respiratory system where gaseous exchange occurs. However, the outlet concentrations were low and would further be diluted by wind in full scale applications. In conclusion, this study shows that biofilters designed and operated for odour degradation can also achieve significant bioaerosol control in waste gas.

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## 1. Introduction

With continuous emphasis on meeting the landfill diversion targets in the UK as established in the Landfill Directive (1999/31/EC) and with the launch of the Landfill Allowance Trading Scheme (LATS) in 2004 (Calaf-Forn et al., 2014), there has been an increase in the number of waste management facilities (Stagg et al., 2010; Environment Agency, 2017). Some of these facilities are enclosed, and can include mechanical biological treatment (MBT), in-vessel composting (IVC), anaerobic digestion (AD) and materials recovery facilities (MRF) or combinations of different waste management systems. These facilities, while achieving cutting edge recycling performance and value recovery from waste streams, have the potential for air pollution within the facility and externally via their extract ventilation especially due to odour and bioaerosol emissions.

Bioaerosols, which comprise predominantly plant pollen, microorganisms (viable or non-viable) and/or microbial

metabolites, have the potential to cause health problems in exposed persons with symptoms such as irritation of the respiratory tract and eyes, coughing, wheezing, tiredness, rashes on skin, diarrhoea, asthma, headache, allergic rhinitis and hypersensitivity pneumonitis (Husman, 1996; Menetrez et al., 2009). Studies show that bioaerosol exposure can cause ill-health in exposed population (Douwes et al., 2003; Searl, 2008; Pearson et al., 2015) Lower forced vital capacity was reported in exposed compost workers ( $n = 190$ ) than in controls ( $n = 38$ ) (van Kampen et al., 2012). Hambach et al. (2012), while assessing work-related health symptoms among compost workers, reported elevated proportion of exposed group ( $n = 31$ ) presenting with respiratory symptoms (29.0%), eye, nose and throat irritation symptoms (35.5%), gastrointestinal symptoms (29.0%) and skin rashes (20.0%) as against the control group ( $n = 31$ ) who showed 3.3%, 13.3%, 6.7% and 0.0%, respectively, for these symptoms. The risk of waste workers' exposure to bioaerosols may be dependent on the work task (mostly indoors for enclosed facilities), their proximity to the source of bioaerosols and the abatement system being used on site (Stagg et al., 2010).

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In the UK, the Environment Agency (EA) is responsible for regulating waste management facilities, usually done through the granting of Permits to Operate. Part of the EA's remit is to ensure that odours and bioaerosols do not adversely impact the surrounding population (Frederickson et al., 2013), and so have included bioaerosol monitoring requirements as an environmental permit condition, and to assess the performance of abatement systems at operation in such facilities (Environment Agency, 2017). The EA gave a precautionary guidance for composting operators when applying for operating permits. This guidance stipulates that concentrations of bioaerosols (as predicted or measured directly) need to be maintained no higher than acceptable levels at 250 m from the composting site or the nearest sensitive receptor (such as a dwelling or workplace which is not part of the composting site), whichever is closer (Environment Agency, 2010). These acceptable levels have been defined as 500 cfu m<sup>-3</sup>, 1000 cfu m<sup>-3</sup> and 300 cfu m<sup>-3</sup> for *Aspergillus fumigatus*, total bacteria and Gram-negative bacteria, respectively, as measured by the standardised monitoring protocol (i.e. the AfOR protocol later replaced in 2017 by the M9 protocol). However, an updated regulatory position statement (RPS) on monitoring bioaerosols at regulated facilities was provided by the EA in January 2018, and excluded the reporting of Gram-negative bacteria (Environment Agency, 2018). In the UK, there are no regulatory occupational limits for bioaerosols at the acceptable levels stated above are not based on dose-response relationships (Pearson et al., 2015). However, the Control of Substances Hazardous to Health (COSHH) Regulation issued by the Health and Safety Executive (HSE) provides employers with the requirements for assessing, monitoring and controlling the exposure of employees to hazardous substances at work environments (HSE, 2013), and thus, applies to workers in waste handling facilities. In Germany, there is a regulatory occupational limit of 50 000 cfu m<sup>-3</sup> for mesophilic fungi (including *A. fumigatus*) in breathable air within the workplace (BAUA, 2013 cited in Pearson et al., 2015).

Biofilters have been used as an abatement method in the waste management industry for many years with varying degrees of success. Biofilters are three phase bioreactors (gas, liquid, solid) composed of filter beds which have high porosity; high buffer capacity; high nutrient availability and high moisture retention capacity which altogether provide suitable internal environments that support the growth and attachment of a mixed-culture of pollutant-degrading microorganisms (Elias et al., 2002; Dastous et al., 2005). Biofilters offer a cost-efficient and potentially environmentally friendly alternative to traditional air treatment technologies, particularly for odour and gas treatment because of the low energy requirement; relatively low construction cost; no generation of secondary pollutants that require subsequent disposal; and capacity to treat a broad spectrum of gaseous compounds (Devinny et al., 1999; Fulazzaky et al., 2014). Biofilters are a method of biological air treatment systems that utilise populations of microorganisms to convert certain organic and inorganic pollutants into compounds and/or forms that are less toxic and/or odourless. The microbial population, which may be dominated by a single species or be composed of different interacting species, employ oxidative, and sometimes, reductive reactions to convert the airborne pollutants into CO<sub>2</sub>, water vapour, and to increase their population using these pollutants as energy and carbon sources (Fletcher et al., 2014). The design and operation of the early biofilter systems were based on a very basic understanding of their method of operation. Although in recent years the structural materials used for biofilters have become more sophisticated, and in the UK there is a move towards using emission stacks, the fundamental design criteria have changed very little (Fletcher et al., 2014).

Several studies have been carried out over the past two decades, in an attempt to better understand the principles of biofilter design

and operation to achieve significant odour and bioaerosol removal. Some of these have looked at the microbiology of the biofilters (Juteau et al., 1999), technical characteristics (Pagella and De Faveri, 2000), performance (Jorio et al., 2000), modelling (Alonso et al., 1999), and economic viability (Gao et al., 2001). It is acknowledged that biofilters offer a versatile and cost effective option for the management of contaminated air from waste handling and treatment facilities (Devinny et al., 1999; Kummer and Thiel, 2008; Frederickson et al., 2013). However, there is a lot of contradictory data and many gaps in the knowledge which need to be addressed if biofilters are to be designed to effectively control all emissions and to perform efficiently. In particular several authors have suggested that media characteristics such as porosity, moisture content, nutrient content, temperature and water retention capacity are the most important factors governing biofilter performance, although the optimum ranges quoted in the literature vary significantly from one author to another (Devinny et al., 1999; Nicolai and Janni, 2001a; Quigley et al., 2004; Schlegelmilch et al., 2005; Álvarez-Hornos et al., 2008; Frederickson et al., 2013). Other authors suggest that operating parameters such as empty bed residence time (EBRT), contaminant loading rate and upflow or downflow configuration are important factors but again there seems to be little consensus as to what the optimum ranges are (Leson and Winer, 1991; Lu et al., 2002; Chen and Hoff, 2009; Liu et al., 2009).

Recent studies by Frederickson et al. (2013) and Fletcher et al. (2014) have evaluated the performance of laboratory-scale and full-scale biofilters in terms of their capacity for simultaneous control of odour and bioaerosols by considering what parameters were vital in defining what design, conditions and maintenance schedules were required for optimum performance. However, these studies concluded that the literature contains apparently contradictory information regarding the impact of biofilter design and operating parameters (such as empty bed residence time, moisture content, media pH and temperature) on odour and bioaerosol emissions and removal. This is a major issue for waste management operators and regulators as there is no clear guidance in terms of design and operating parameters that would provide a robust evidence base against which to benchmark the effectiveness of existing biofilters and future abatement system proposals including biofilters. Although bioaerosols removal mechanisms by biofilter have been thought to include inertial deposition, diffusional (or Brownian) deposition and flow line interception (Ottengraf and Konings, 1991), Frederickson et al. (2013) recommended that further research is required to determine the relationship between odour and bioaerosol emissions from biofilters to determine the extent to which biofilters may be used to effectively reduce both odour and bioaerosols, and to identify best practice techniques for optimising biofilters to maximise control of both odour and bioaerosol emissions. This is especially necessary because of the differences in the removal mechanisms of odour and bioaerosols. Literature suggests that odour removal mechanisms is dependent on sorption of the odorous compounds into the biofilm layer on the media surface where biodegradation takes place, a function which relies on long residence time; whereas bioaerosol removal is achieved via particle impaction onto the media particles, and so an extended residence time may not impact positively on removal (Devinny et al., 1999; Fletcher et al., 2014). Thus, it is imperative to develop a better understanding of biofilter design and effective performance monitoring techniques especially if they are to continue to control all emissions and achieve their full potential.

This study was aimed at investigating the performance of pilot-scale biofilters for removal of bioaerosols from waste airstreams from a materials recovery facility (MRF) which acted as a source of bioaerosols. The objectives of this research were: (1) to assess

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