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Research article

Trickling filter technology for biotreatment of nitrogenous compounds emitted in exhaust gases from fishmeal plants

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Highlights

- Methylamines and ammonia are nitrogenous compounds causing environmental nuisance.
- First study addressing biotreatment of gaseous methylamines in the fishmeal industry.
- Biotreatment of volatile amino-compounds using lab-scale biotrickling filters.
- Trimethylamine was removed at a capacity of 88 mg N m^{−3} h^{−1} (92% efficiency).
- Heterotrophic ammonia-oxidizing bacteria were identified as promising candidates.

Abstract

Odour emissions are a major [environmental issue](#) associated with fishmeal production. Laboratory-scale biotrickling filters (BTf)s were inoculated with [microbial consortia](#) derived from [sewage sludge](#), with the goal to study the biotreatment of low-loads of methylamines and ammonia that are main components of odorous exhaust gases produced by fishmeal processing plants. A BTf packed with ceramic rings was subjected to a real fishmeal plant emission containing trimethylamine (TMA), dimethylamine (DMA) and monomethylamine (MMA). The highest elimination capacities (ECs) obtained were 372 mg TMA m^{−3} h^{−1}, 5.518 mg DMA m^{−3} h^{−1} and 1.038 mg MMA m^{−3} h^{−1}, with maximal removal efficiencies of 92% (TMA), 83% (DMA) and 95% (MMA) after 30 days operation. In a different experiment, a [polyurethane](#) foam packing was employed to treat ammonia (NH₃) at low inlet loads, reaching an EC of 47.19 mg N m^{−3} h^{−1} with 99.8% efficiency (inlet load of 47.27 mg N m^{−3} h^{−1}). Likewise, the [microbial community](#) of the polyurethane-associated biofilm was diverse and stable during operation. These results suggested that elimination of volatile amino-compounds using BTf)s inoculated with a methylophilic microbial consortium holds potential for odour removal. In addition, sequencing analysis of 16S rDNA gene fragments allowed the identification of heterotrophic ammonia-oxidizing bacteria that are promising candidates to effectively maintain ammonia elimination in a biotreatment operation of nitrogenous compounds present in exhaust gases from fishmeal facilities.

Introduction

Fishmeal processing plants may cause environmental nuisance in near residential areas, creating a poor perception of the facility activities. The largest odour emissions are generated in fishmeal dryers, and in a lesser degree during cooking, pressing and separation processes. Pollution by malodours from fishmeal factories is not considered a serious hazard to health, however; its exposure may cause discomfort and several health effects (Clausen et al., 2013). Trimethylamine (TMA), dimethylamine (DMA), monomethylamine (MMA) and ammonia are reduced nitrogen compounds commonly found in exhaust gases from fishmeal processing plants (Caraway et al., 2007; Seo et al., 2011), and are also released by wastewater treatment plants (Wang et al., 2014), waste disposal landfills and livestock farming/animal husbandry (Sintermann et al., 2014). Aerial exposure to aliphatic amines causes local irritation (EPA, 2008). Furthermore, in the atmosphere these compounds may be photochemically converted to nitrosamines, which are toxic and carcinogenic (Lee and Wexler, 2013).

TMA is a pungent volatile amine responsible for the “fishy” odour that arises from bacterial reduction of the trimethylamine-N-oxide present in marine fish (Chun et al., 2014), which has a detection threshold of 0.26 ppbv (van Gemert, 2011). This compound has been detected in fishery industrial facilities at 20.6 ppbv (Seo et al., 2011), therefore; it is imperative that control technologies for the abatement of malodours are highly effective at treating low concentrations of air pollutants. Biological treatments have been proposed as efficient, cost-effective and environmental friendly alternatives for the treatment of air containing low concentration of contaminants, which are metabolized to simple end-products (Barbusinski et al., 2017).

In this study we employed biotrickling filters (BTf)s inoculated with microbial consortia derived from sewage sludge to assess the removal of methylamines (TMA, DMA and MMA) and ammonia (NH₃). BTf)s are packed-bed columns with a microbial biofilm established on the surface of an inert packing material and a liquid phase that is recirculated through the reactor bed (Schiavon et al., 2016). This technology has been applied to treat air containing reduced sulphur compounds and nitrogenous compounds, since it offers better control over pH and environment conditions of the active biofilm and it also allows to remove pH-relevant metabolites (acid by-products) that are accumulated in the filter bed during the bio-oxidation process, causing biomass inhibition (Aroca et al., 2007). However, previous studies on TMA removal using BTf)s focused on the treatment of high inlet loads of synthetic gas streams containing the pure compound (Aguirre et al., 2018; Wan et al., 2011; Wei et al., 2015). This condition is not representative of the fishmeal industry, since the exhaust gases contain methylamine mixtures (TMA, DMA and MMA) at ppmv-level concentrations plus the presence of dimethyl sulfide (DMS) and other volatile organic compounds (VOCs) that may compete for TMA elimination (Caraway et al., 2007). Thus, to the best of our knowledge this is the first study addressing the biotreatment (BTf) of methylamines in the context of a real odorous emission from a fishmeal industrial plant.

We further characterized the biotreatment of low ammonia loads using a BTf packed with polyurethane foam, since this compound is produced as an oxidation product of the metabolization of methylamines, having the potential to inhibit gas treatment (Ding et al., 2007; Ho et al., 2008). The removal of high inlet loads of gaseous ammonia has been

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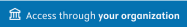
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reported with autotrophic nitrifiers (Ramirez et al., 2009; Chung et al., 2000). However, heterotrophic ammonia-oxidizing bacteria have the potential to adjust better to odour emission conditions of the fishmeal industry, which generates methylamines at low concentrations (ppbv-level) and discontinuously, only during industrial production periods. Importantly, these microorganisms have shown to outperform autotrophic bacteria in their ability to grow at low ammonia concentrations and to recover biologic activity after deprivation of this compound (Bollmann et al., 2002; van Niel et al., 1993). Therefore, with the aid of molecular techniques we investigated the composition of the bacterial community of the polyurethane-associated methylotrophic consortium that was exposed to low concentrations of ammonia, with the aim to identify heterotrophic ammonia-oxidant bacteria that can contribute to maintain ammonia elimination in a biotreatment operation of methylamines emitted in exhaust gases from fishmeal plants.

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Section snippets

Inoculation and culture media

Aerobic activated sludge from the secondary sedimentation tank of a waste water treatment plant in the city of Concepción, Chile (ESSBIO S.A.) was employed as the microbial inoculum. About 500 mL of the concentrated sludge were suspended and cultured in two culture media based on glucose and methanol as a carbon source. The glucose medium contained (per liter) glucose 5.63 g, (NH₄)₂SO₄ 2.67 g, KH₂PO₄ 0.29 g, MgSO₄·7H₂O 0.19 g, and the methanol medium (per liter) K₂HPO₄ 3 g, KH₂PO₄ 3 g, NH₄Cl ...

Methylamines removal

The average concentrations of TMA, DMA and MMA in the exhaust gases stored in the buffer tank were 4.005, 0.086 and 0.021 mg N m⁻³, respectively, corresponding to 1.6 ppmv, 46 ppbv and 16 ppbv. The highest REs obtained for TMA, DMA and MMA after 30 days of operation were 92%, 83% and 95%, respectively (Fig. 2 and Table 1). Similar REs were reported by Ho et al. (2008) for TMA (85%), DMA (90%) and MMA (97%), using a BTF inoculated with *Paracoccus* sp. and *Arthrobacter* sp.

Fig. 3 represents the EC ...

Conclusion

Nitrogen-containing compounds typically contained in exhaust gases from fishmeal plants can be removed with high efficiency using BTFs inoculated with specialized microbial consortia. Methylamines were eliminated at 82–96% efficiency, reaching for TMA a critical EC of 88 mg N m⁻³ h⁻¹ (92% efficiency), while ammonia removal reached efficiencies of 99.8% at an inlet load of 47.27 mg N m⁻³ h⁻¹. The bacterial population in the polyurethane-associated biofilm was characterized by DGGE, showing a ...

Conflicts of interest statement

The authors declare no conflicts of interest. ...

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...Each of the equipment types has its advantages and disadvantages, and specific ranges of economic application (Mudliar et al., 2010); however, biotrickling filters stand out as being compact, moderately costly and well suited for those applications in which operational flexibility is required (Wu et al., 2018). Although biotrickling filtration is not a new technology, it still is considered as innovative one and new application areas are entered rather slowly (Oyarzun et al., 2019). In conventional biofilters and biotrickling filters, the pollutant to be treated is initially absorbed by the aqueous film that surrounds the biofilm and then the biodegradation takes place within the biofilm where the microorganisms metabolize the pollutant (Kennes and Veiga, 2001)...

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