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Research Paper

Biofiltration of exhaust air from animal houses: Evaluation of removal efficiencies and practical experiences with biobeds at three field sites

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Three wood-chip based biofilters ('biobeds') with media depth of 0.25 m were monitored during 6–12 months (capacity and surface area for biofilter #1: 75,000 $m^3\ h^{-1}$ from poultry manure dryer, 68 m^2; biofilter #2: 100,000 $m^3\ h^{-1}$ from pig house, 188 m^2; biofilter #3: 300,000 $m^3\ h^{-1}$ from pig house, 440 m^2). Average empty bed residence times (EBRT) were 1.4, 2.6, and 3.3 s; average pressure drops were 287, 22, and 91 Pa, respectively. Average ammonia (NH_3) and odour removal efficiencies per site were 38–74% and 43–62%, respectively; a large variation was found between measurements. Poor moisture control of the packing material decreased these efficiencies (breakthrough). Average fine dust (PM_{10}) removal was mostly 90% or higher. It was found that a significant part of the NH_3 may be converted to nitrous oxide (N_2O), a potent greenhouse gas. At one site even 21% of all NH_3-N was converted to NO_2-N. It is the first time that such high average N_2O production rates have been reported for long-term monitoring of biofilters. It is concluded that biofilters have potential for emission reduction at animal houses, but especially high pressure drop (clogging/fouling) and homogeneous moistening of the biobed need attention. To prevent breakthrough of air at dry spots, it is recommended to increase the media depth. Further research is necessary to explore the conditions and parameters that influence N_2O production in this type of systems, as currently no control strategy is available for preventing N_2O generation.

1. Introduction

Intensive livestock production is connected with a number of environmental effects which include ammonia (NH_3), odour, and fine dust (PM_{10}) emissions from animal houses. For mechanically ventilated animal houses, one of the available mitigation techniques is end-of-pipe treatment of the ventilation air. In several European countries (like the Netherlands and Germany) packed-bed air scrubbers (both acid scrubbers and biotrickling filters) are applied on a large scale for this purpose. However, as compared to ammonia, the odour and PM_{10} removal efficiencies are often relatively low for scrubber systems (Melse & Ogink, 2005; Melse, Hofschreuder, & Ogink,

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2012a). Another possible end-of-pipe mitigation technique is the use of a biofilter (or biobed), which might achieve higher efficiencies for odour and PM_{10} (Arends et al. 2008; Chen & Hoff, 2009, 2012; Dumont et al. 2014a; Nicolai, Clanton, Janni, & Malzer, 2006; Van der Heyden, Demeyer, & Volcke, 2015).

In contrast to most scrubbers, a biofilter has an organic-based packing material or medium (e.g. a mixture of materials such as compost, wood bark, wood chips, peat, perlite, and organic fibres) that is intermittently wetted. Biofilters are used in many industrial sectors (food industry, paint and lithographic industry, waste water treatment etc.), but full-scale applications on farms are scarce. In a biofilter, water is distributed on top of the packing material usually by spray nozzles. Contaminated air is introduced into a pressure plenum underneath the bed and flows upwards (counter-current) through the bed, resulting in intensive contact between air and moist packing material, enhancing mass transfer of pollutants from gas to liquid phase. The air that leaves the biofilter is usually water saturated; any excess water might be discharged from the pressure plenum.

Ammonia removal takes place by nitrifying bacteria that grow on the moist packing material. As in a biotrickling filter, the ammonia dissolves in the water phase and is converted to nitrite and nitrate by a bacterial process called "nitrification". These compounds are removed with the percolate water as dissolved NH_4NO_2 and NH_4NO_3 and to some extent also are accumulated in the organic packing material. In anaerobic zones in the biofilter denitrification can also take place, meaning that part of the nitrite and/or nitrate is converted to nitrogen gas (N_2). Furthermore, nitrous oxide (N_2O) might be produced in the biofilter as a by-product from both nitrification and denitrification. N_2O is a strong greenhouse gas (GHG) with a Global Warming Potential (GWP) of 298, which means that 1 kg of N_2O has the same impact as 298 kg of CO_2 on a time horizon of 100 years (IPCC, 2007).

Due to stricter odour and fine dust emission standards, there is a renewed interest in application of wood-chip based biofilters in livestock production in the Netherlands. The biobeds that are currently being built are of a new type that contains a layer of only 0.25 m of wood-chips as packing material, whereas normally a bed layer thickness of 0.5–1.0 m had been used. This was done to reduce the pressure drop over the filter, but a thinner bed layer might also reduce the effectiveness of the moistening system. In order to test this new design approach, one-year performance trials were carried out at three full-scale biofilters used for treatment of animal house ventilation air, one at a poultry and two at pig farms. The aim of the research was to determine the performance of these biofilters with regard to removal of ammonia, odour, and fine dust (PM_{10}), and to assess the possible generation of GHGs, *i.e.* methane (CH_4) and N_2O.[1] Furthermore, the operational stability was evaluated, especially with regard to the humidification of the bed.

[1] Data from this study was reported earlier in 3 measurement reports in Dutch (Melse & Hol, 2012; Melse, Hol, Nijeboer, & Van Hattum, 2014; Melse, Hol, Ploegaert, Nijeboer, & Van Hattum, 2015).

2. Materials and methods

2.1. Description of biofilter sites

The performance of three biofilters was monitored for a period between 6 and 12 months. One of the biofilters (#1) was located at a laying hen house (30,000 animal places) where an external manure drying unit was connected to the ventilation outlet of the barn. In this unit poultry litter and droppings were collected on a permeable cloth and part (about 1/3) of the warm exhaust air of the house was forced through the cloth with fans, resulting in rapid drying of the litter. Next this air was led through the biofilter. The remaining 2/3 of the exhaust air was released untreated. Biofilter #2 was used for treatment of exhaust air of a fattening pig house (1300 animal places). Biofilter #3 treated air from three pig houses, with in total 1600 rearing pig and 4300 fattening pig places, that were all connected to the biofilter pressure plenum. In Fig. 1 a schematic of the biofilter design is given; all biofilters were designed and built by the same company.

All biobeds were rectangular and consisted of a 0.25 m thick layer of organic material, mainly consisting of wood chips (size: 20–30 mm). For biofilter #1, there were also some finer particles of wood and bark present between the wood chips; for biofilter #2 and #3, the finer fraction was sieved out prior to filling the biofilter. The bulk density of the material was about 600 kg m^{-3} at a dry matter content of about 30%. Underneath the bed was a pressure plenum (height: 0.50 m) where the air was introduced. The biobed was humidified by spray nozzles placed on the surface of the bed. The spraying system was controlled by a timer and usually operated for 3–6 min per hour. If necessary, the spray time settings were adjusted by the operator after weekly visual inspection of the biobed conditions. The percolate water that accumulated in the pressure plenum was removed by pumps. Above the biofilter, an inclined roof was installed to diminish weather influences (rainfall and blazing sun light) in order to promote stable humidity conditions in the bed. Every two months, all biofilter sites were visited and measurements were carried out. The biofilters were located in the Netherlands, which has a moderate marine climate; measurements were carried out

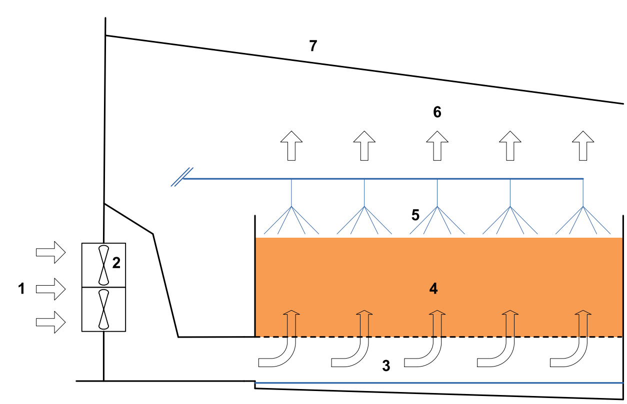

Fig. 1 – Schematic of biofilter (cross-section); 1: inlet air; 2: fans; 3: pressure plenum; 4: layer of wood chips; 5: sprinklers, 6: outlet air; 7: roof.