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Using biofilters for treating exhaust air from livestock buildings

Results from a nitrogen balance

A biofilter of the most simple construction was tested over five months and a nitrogen balance carried out in an evaluation of biofilter performance with livestock building exhaust air containing ammonia. With an 86.3% nitrogen recovery rate the results showed that 31.6% of the nitrogen registered was released as gas emissions from the biofilter, 26.2% accumulated in the biofilter material and 28.5% in the sump water. Nitrification and denitrification processes led to the release of considerable amounts of nitrogen and nitrous oxides. Nitrogen accumulation and marked acidification of the filter material meant that no stable biofilter action could be achieved.

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Correctly dimensioned biofilters are well suited for reducing odour emissions. But are such filters suitable for long-term treatment of barn air with comparatively high ammonia content? What happens to the introduced ammonia? To answer these questions a trial biofilter had exhaust air passed through it from a feeding pig plant over 148 days and a nitrogen balance was conducted.

Trial facilities, method and analytic

The trial biofilter comprised a 2 m high Plexiglas column with an inner diameter of 0.29 m (*fig. 1*). It was applied in the exit airflow. Biofilter material comprised bark mulch (35 l) piled to a total height of 0.53 m with the pile separated into two segments each of 0.265 m. The irrigation of the filter material was via a full cone jet with a time controlled pump operating at 6 h intervals. The sump was filled with 8 l of tap water at trial begin. The scale-determined water loss (evaporation loss via exhaust air, samples) was regularly replaced with deionised water. With filter volume occupation of 57 and 151 $m^3/(m^3\ h)$ gas velocity was 0.008 m/s in the first 55 trial days and 0.026 m/s for the remainder of the trial period. Crude and pure case composition was analysed for the parameters ammonia, nitrogen oxide and nitrous oxide over the total trial period in 3 h rhythm and converted to nitrogen. From the respective concentration averages per day and the volume flow, the average mass flow for every component was calculated and totalled in terms of crude and pure gas. The determination of nitrogen concentrations and masses (NH_4-N, NO_2-N, NO_3-N, Kjeldahl-N) in the sump took place before trial begin and then in each case three times in the week. The nitrogen removed with the samples was added to the sump total. The nitrogen concentrations and masses in the filter material were investigated before trial begin and then after 61, 89 and 148 d whereby in each case total material was removed and mixed before a mixed sample was prepared from ten individual samples and then analysed.

Results

The applied filter material which was not inoculated with biomass contained at trial begin 0.8 g NH_4-N and 4.6 g Kjeldahl-N but neither NO_2-N nor NO_3-N. In the sump water was only a mass of 0.1 g NO_3-N. pH value was 4.7 (bark mulch) and 6.8 (sump water). With an average crude gas concentration of 7.5 ppm NH_3, 0.1 ppm NO_x and 0.65 ppm N_2O, 20.4 g of NH_3-N, 0.05 g of NO_x-N and 3.1 g of N_2O-N were registered in the system in the first trial period (0 to 61 d) (*fig. 2*). Determined in the pure gas was 1.1 g of NH_3-N, 0.3 g of NO_x-N and 3.9 g of N_2O-N. Ammonia precipitation from the biofilter in this period was over 95% whilst the nitrogen emissions rose by 500% and the

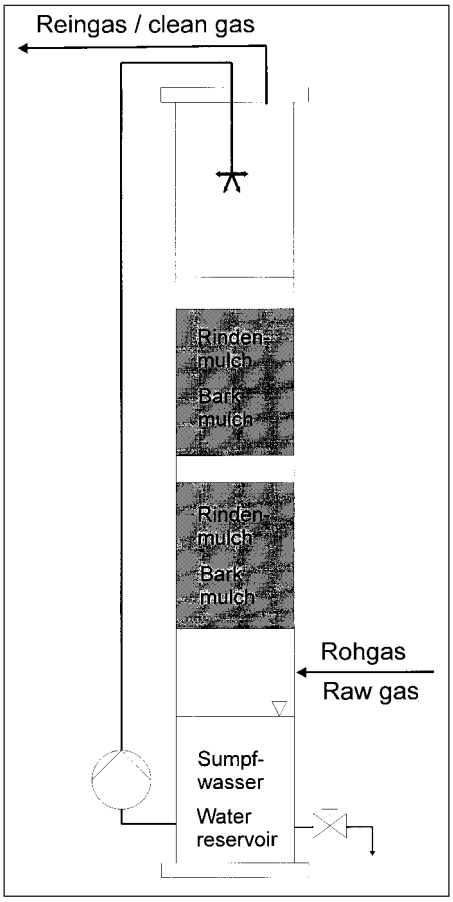

Fig. 1: Biofilter test facility

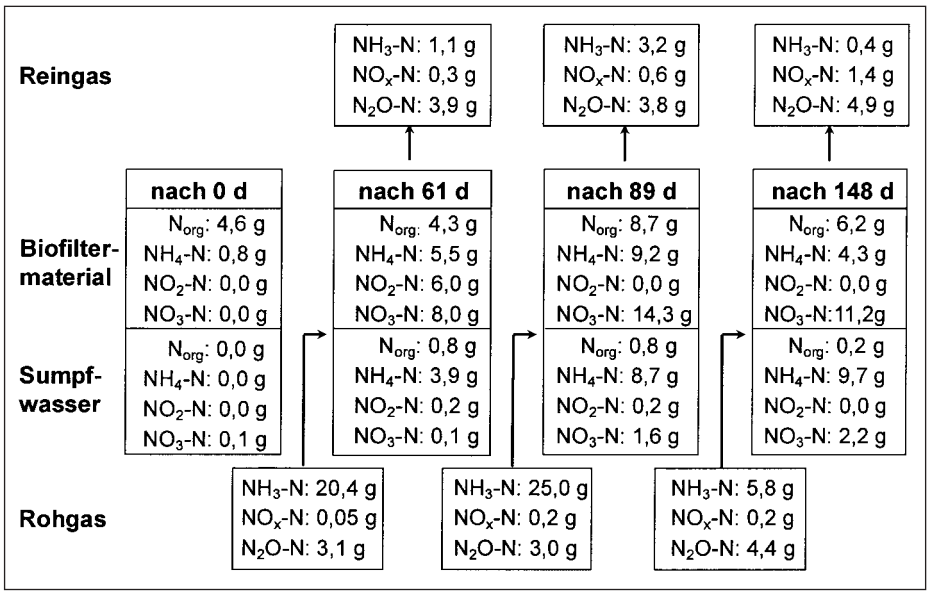

Fig. 2: Nitrogen flow in the biofilter

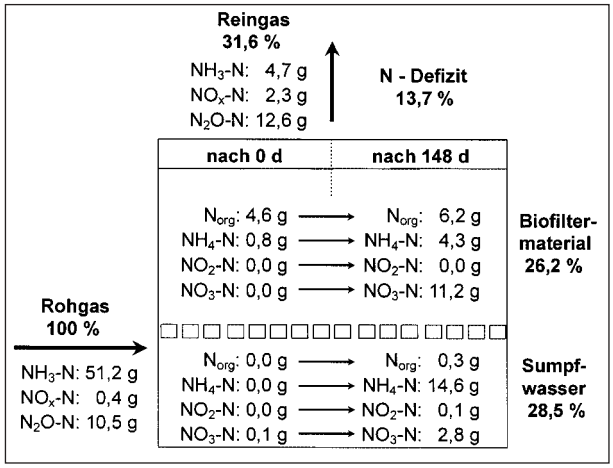

Fig. 3: Nitrogen balance of the biofilter

nitrous oxide ones by 26%. The increased nitrogen oxide and nitrous oxide emissions can be attributed to the microbial ammonia oxidation (nitrification). Thus the nitrite and nitrate content rose in the biofilter material. Notable was that in the sump water only limited amounts of these nitrogen fractions could be determined, i.e. hardly any leaching resulted from the irrigation of the biofilter. The ammonia content rose substantially in the biofilter material as well as in the sump water. This was attributable to non-quantitative nitrification. Because of the excess input of ammonia, pH in the filter material was 8.0 and 8.3 in the sump water.

In the second trial period (61 to 89 d) a further 25 g NH_3-N, 0.2 g NO_x-N and 3.0 g of N_2O-N were registered in the system. The ammonia precipitation dropped to 87% despite sinking pH value in filter material and sump water. The nitrogen oxide emissions rose by 200% and those of nitrous oxide by 27%. The nitrite which had in the meantime been formed in the biofilter material was completely decomposed whereby mainly nitrate was produced and accumulated in the filter material. Additionally there was a strong increase in ammonia in filter material and sump water whilst the amount of nitrate only increased by a small amount. These findings pointed to the start of a limitation to the ammonia oxidation.

In the last trial period (89 to 148 d) only 5.8 g of NH_3-N, 0.2 g of NO_x-N and 4.4 g of N_2O-N were registered. With an ammonia precipitation of 93% in particular the nitrogen oxide emissions rose (by 600%) during this trial period. The nitrous oxide emissions increased by 11%. Through the low pH in the filter material (4.4) and in sump water (4.7) the nitrification in the system collapsed altogether.

The nitrogen balance over the whole period showed that 31.6% of the nitrogen registered in the biofilter was once again released as gas emissions (*fig. 3*). Nitrogen oxide emissions rose by 475% and those of nitrous oxide by 20%. Based on the emission factors 1 kg Nr. (NH_3-N + NO_x-N) represented 3.83 kg CO_2 and 1 kg of N_2O-N represented 296 kg of CO_2. In the conducted trial 46.5 g NH_3-N separated and 1.9 g NO_x-N as well as 2.1 g N_2O-N were additionally produced. Accordingly, through the NH_3-N separation 0.18 g of CO_2 equivalent was reduced. However, through the creation of NO_x-N 0.007 kg, and through the nitrous oxide production, 0.62 kg of CO_2 equivalent was newly created. From the aspect of climate protection the single step biofiltration could be judged as negative.

26.2% of the registered nitrogen was accumulated within the biofilter material whereby strong nitrate enrichment could be especially observed. Where nitrate concentrations were high this also led to nitrification limitations as with low pH which resulted from the nitrification (production of nitric acid). With low oxygen content (reducing or stopped ventilation, increasing solidifying of the biofilter material) denitrification occurred through which nitrate converted to elementary nitrogen (N_2), nitrogen oxides and nitrous oxide (*fig. 4*). In this case through failing to fulfil a filter throughflow of 20 m^3 /(m^3 h) 20% of the registered NH_3-N was converted to N_2O-N. This result also speaks against using a single stage biofilter for barn exhaust air cleaning.

Accumulated in the sump water was 28.5% of the registered nitrogen, mainly as ammonia (fig. 3). Through regular changing of the water the nitrogen in the sump water could be removed from the system and thus the already described procedure in the biofilter postponed. For this, however, considerable wash water amounts would be required, the storage of which would necessitate the enlarging of the slurry container capacity. High water content in biofilter material additionally has a negative effect in odour reduction.

The recovery rate of the registered nitrogen was sufficient at over 86%. Main reason for the low findings could be denitrification processes which also led to the production of elementary nitrogen (N_2) and could not be recorded.

Conclusion

According to the available results the use of simple biofilters for cleaning of barn exhaust air cannot be recommended. The separation of ammonia from exhaust air leads in the biofilter to an unregulated and instable nitrification which is associated with the release of nitrogen oxides and the climate-relevant nitrous oxide. Additionally, considerable amounts of nitrous oxide are produced by denitrification where there is not sufficient ventilation of the biofilter.

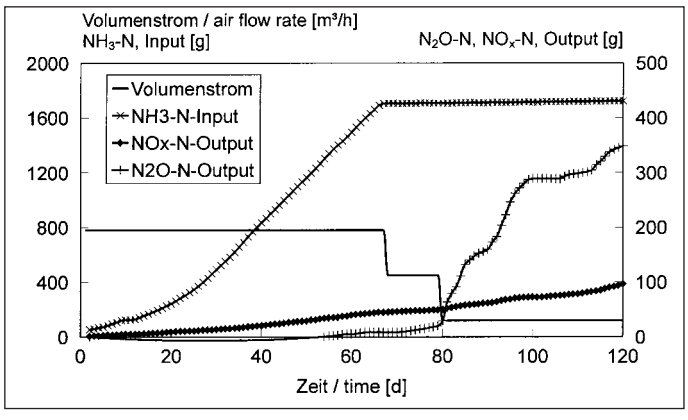

Fig. 4: Release of nitrous oxide from a biofilter by lowering the air flow rate