BIOLOGICAL PURIFICATION OF WASTE AIR IN LIVESTOCK OPERATIONS
- SYSTEM REQUIREMENTS AND LIMITATIONS -

Jens Seedorf

Institute for Animal Hygiene, Welfare and Behaviour of Farm Animals,
University of Veterinary Medicine Hannover, Foundation, Buenteweg 17p, 30559 Hannover,
Germany; Email: Jens.Seedorf@tiho-hannover.de

INTRODUCTION

Airborne emissions from sources such as industry and traffic are able to change considerably the quality of the atmosphere world wide. To avoid, prevent or reduce harmful effects on human health and the environment as a whole, national and international committees are seeking on common strategies to define and establish objectives for ambient air quality (Council Directive 96/62/EC).

In recent years modern farm animal production is also increasingly being regarded as a source of gaseous, odorous and particulate emissions which are all environmentally harmful and a nuisance. Therefore, livestock operations are under increasing pressure to fulfil minimum requirements, and avoid the pollution of the atmosphere. The need of such efforts is underlined by the European Directive on Integrated Pollution Prevention and Control (IPPC), which regards environmental protection as the highest priority. This target has to be reached by the best available techniques (BAT) guaranteeing the lowest emissions possible (Council Directive 96/61/EC). The currently established BAT within livestock buildings such as adapted feeding regimes (i.e. nitrogen reduced multiphase feeding for fattening pigs), specific manure techniques (i.e. conveyor belt systems in laying hen houses to increase dry matter in feces) or adjusted ventilation rates to minimize transboundary effects at manure surfaces (i.e. higher air velocities are increasing volatilization of gaseous compounds) are nearly exhausted in terms of their current effectiveness. Despite this progress, pollution caused by livestock production facilities is still significant. Odour as potential psychogenic component, ammonia as acidifying agent of soils, methane as contributor to climate change or dust as respiratory risk factor are only a few examples. Therefore, the existing environmental quality standards need stricter enforcement. In regions with high farm animal densities and low ambient air quality new farm buildings get building permission only when biological waste air purification systems (BWAPS) are in place such as biofilters or bioscrubbers.

In contrast to the increasing interest in BWAPS there is limited knowledge on the strenghts and weaknesses of such systems. In recent years some investigations on the efficiencies and limitations were carried out. This report gives a short overview about the most common BWAPS in livestock operations and outlines operative characteristics related to biosecurity of such BWAPS and environmental hygiene demands.

APPLIED SYSTEMS

Physical gas purification systems (i.e. cyclones, thermal and catalytic combustion) are well known techniques for reducing environmentally harmful agents such as particulate matter and noxious gases in industry, while BWAPS are the most important techniques in agriculture.

They are used to reduce potential components in the exhaust air of forced ventilated livestock buildings such as odour, ammonia and dust as the most important target components, which have to be reduced significantly according to legislation. Most important in all BWAPS are settled and sessile microorganisms, which are responsible for the reduction of gas components by their oxidative metabolic capacities.

In principle four different techniques can be principally distinguished [1], which are briefly characterised.

Biofilter

Biofilters contain organic material (bark, peat, wood shavings, heather, compost material etc.) carrying sessile microorganisms, which utilize both components of the carrier material and the components dispersed in the waste air. This two-way utilization of nutrients is advantageous, because fluctuations in the concentration of nutritive components in the waste air are compensated by the other source. The number of active microorganisms and their metabolic degradation capabilities are consequently not diminished and the effectiveness of the system does not decline. In all BWAPS water plays a crucial role for microbial activity, transport of nutrients and removal of toxic degradation products. Therefore, permanent water irrigation of the filter material and humidification of the waste gas in pre-scrubber units are carried out (Fig. 1). Specific problems are caused by the high amounts of airborne dust in livestock buildings. It is essential to remove this dust before the waste air is passing the biofilter to avoid clocking of the biofilter.

Biotrickling reactor

In a trickle bed reactor the contaminants from the waste air are passing an inert packing material, which is permanently sprinkled by water from above. The large surface of the packing material is fully covered by a biofilm of microorganisms, which remove and metabolize the components/nutrients from the air (Fig. 2a). A disadvantage is that the inert material does not contain nutrients. Therefore, the material have to be frequently flushed with soluble nutrients to support a stable biofilm. Furthermore, pH adjustment is also necessary to guarantee sufficient purification efficiency.

Bioscrubber

A bioscrubber consists of an absorber unit where the interaction between waste air and activated sludge takes place and a fermentation tank where the sludge is aerated and conditioned (water, pH etc.). A cycle pump is continuously transferring the sludge between absorber and fermentation tank. Excess sludge and water leave the fermentation tank by an overflow and run into a slurry pit, for instance (Fig. 2b). The air velocity in the absorber column can be increased up to 2 m/sec which is more than in the other systems. By the very close contact of sludge and waste gas bioscrubbers are well suited for purification of heavy polluted air and the efficiency to remove water soluble components is very high.

Combined systems

There are existing numerous combinations of the BWAPS described above. Very often combined systems can reduce airborne pollutants much more effective than single step purification can do. Figure 3 shows a cascade of different filter walls (F) and water irrigation zones within a multi-step system which is very effective to remove dust (F I), ammonia (acidified water, F II) and odour (B=biofilter).

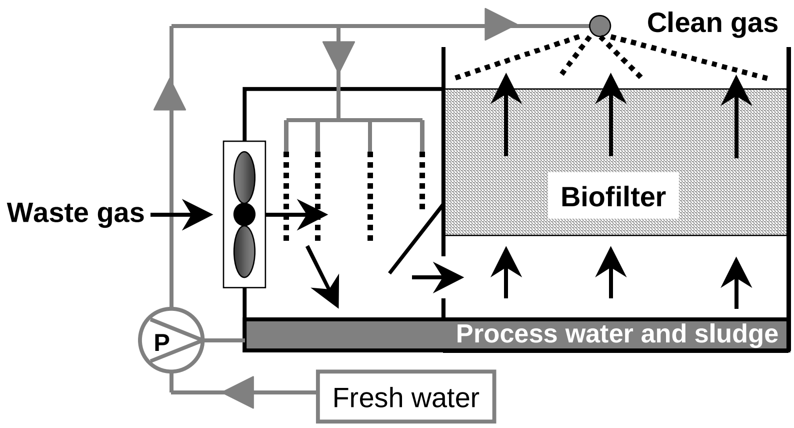

Fig. 1: Technical principle of a biofilter. Waste gas is sucked in by fans, passes a wet scrubber unit (i.e. rack of sprinkler nozzles) to remove dust and water soluble components and is pressed through the biofilter material (i.e. wood shavings or inert material, see also biotrickling reactor). Mixture of process water and fresh water is recirculated by a pump (P).

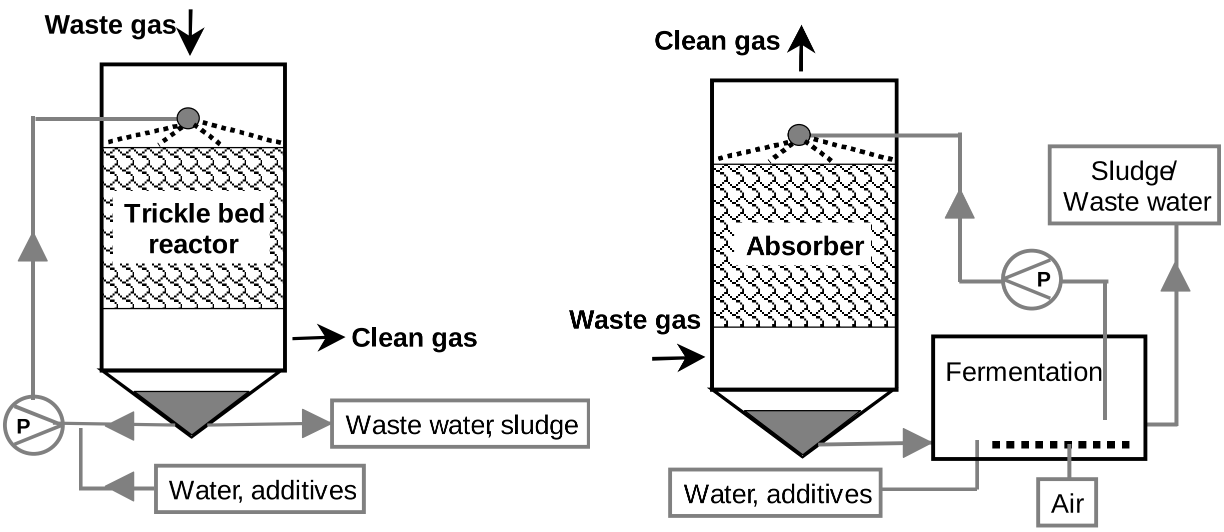

Fig. 2: Scheme of a biotrickling reactor (a) and bioscrubber (b). The waste gas is humidified by water and pressed through the trickle bed reactor (a) with the biofilm. Evaporated water is supplemented and additives (pH regulation) and sludge disposal are essential. In the bioscrubber (b) absorption of pollutants (absorber) and microbial degradation (aerobic fermentation tank) take place at different locations.

REQUIREMENTS

For an effective operation of BWAPS, the supply of system-integrated microorganisms with nutrients is essential otherwise the efficiency declined considerably. A balanced ratio of carbon (C), nitrogen (N) and phosphorous (P) as primary nutrients is important (C:N:P ≈

100:10:1). Usually, the degradable pollutants serve as a source of nutrients containing C, N and P in sufficient amounts to allow biomass growth. But in some BWAPS these basic nutrients are present in the waste air in too low amounts (i.e. carbon content). Therefore it can be necessary to add nutrients if the available organic material is unable to serve sufficiently as natural source of nutrients.

The elimination of pollutants from the waste air is a predominantly time depending process due to the specific kinetics of the microbial enzymes. Therefore, the residence time of pollutants in the BWAPS is a most relevant criteria to make sure that reduction of pollutants takes place as much as possible. Additional parameters (example of effects in brackets) such as temperature (selectivity on psychrophilic, mesophilic and thermophilic microorganisms), humidity of the air (solubility of compounds), structure of biofilter material (balanced surface-volume ratio for sufficient absorption with energetically acceptable gas flow resistance) pH values (inhibition or support of specific microbial populations), oxygen supply (extent of biodegradation in biofilms), air flow velocities and directions (residence time and drainage capabilities for fluids), contaminant loads (steady state operation vs. exponential biomass grow with the need of removal), byproducts (odorous carboxylic acids and aldehydes caused by degradation) etc. determine the biological processes and therefore a proper operation of BWAPS.

Under standard operation conditions minimal reduction efficiencies of 70 % are possible for dust and ammonia. This is true for biofiltration, biotrickling reactors and bioscrubbers. In cascade-like BWAPS the elimination efficiency for dust and ammonia can reach 90 % and more. For odour 300 odour units (OU) per m³ and the non-perception of typical livestock odour in the clean gas is environmentally acceptable and agreed by authorities, which permit livestock buildings.

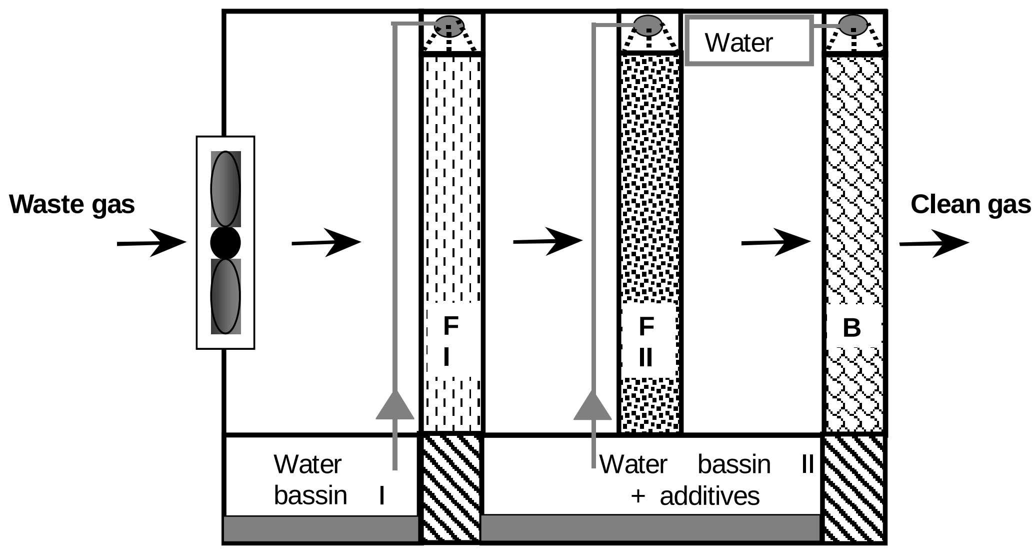

Fig. 3: Waste gas from a livestock building is pressed through a combined purification system. Multi-step elimination of dust, ammonia and odour occur at F I, F II and B supported by rinsed water in each cascade stage.

LIMITATIONS

The complex physical, chemical and biological processes in the BWAPS require frequent monitoring of all relevant process factors to prevent inappropriate operation which does not protect the environment and is economically doubtful. For example, too low oxygen supply can lead to unbalanced nitrification and denitrification reactions and the release of the greenhouse gas nitrous oxide. Highly compressed biofilter material promotes filter break-throughs of untreated waste gas or is enhancing anaerobic degradations with an increase of emitted odour, which may be even worst than the original odour in the waste gas. In contrast to these relatively well documented limitations of BWAPS, little is known about the risk of uncontrolled emissions of system-related microorganisms from such operations.

The microbial ecosystem in BWAPS is influenced by three compartments, namely livestock air, immobilized biofilms and recirculated process water, which connects the two former compartments. Therefore a considerable biodiversity exists due to the permanent intake of microbes via the waste air and due to the reproduction capacities of deposited (process water) and biofilm-related microorganisms (Tab. 1). Apart from the huge amounts of detected microorganisms per ml, health-related microbes such as *Escherichia* coli (smear infection, endotoxin release), *Acinetobacter sp.* (facultative respiratory infection, endotoxin release, high tenacity) or *Aspergillus* sp. (allergenicity) were found. Additionally, pro-inflammatory endotoxins are also significantly concentrated in the process water. In a previous study the highest relative enrichment for endotoxins was seen with 11,300 % in the air within the BWAPS in comparison to the waste air of the animal house [3]. Such a microbiological mixture enriched in the process water is sprayed and aerosolized within the BWAPS for humidifying purposes. It highlights the question of biosecurity both for the operator (farmer) and the environment (residents).

Table 1: Results of microbial spot investigations of process water from a BWAPS installed at a duck fattening unit in comparison to recently published data from a piggery [2].

Sum parameter	**Day 1**	**Day 2**	**Genus/species**	**Day 1**	**Day 2**
in colony forming units (CFU) per ml:			In CFU/ml (approximately):		
Total bacteria	205,000	3,270,000	*Bacillus* sp.	10^5	-
Staphylococci	53,700	517,000	*Pseudomonas stutzeri*	-	10^5
Enterobacteriaceae	5,170	393,930	*Proteus* sp.	10^5	10^6
Fungi 25 °C	17	113	*Acinetobacter* sp.	-	10^6
Fungi 40 °C	13	10	*Escherichia coli*	10^5	-
in Endotoxin Units (EU) per ml:			Coliforme bacteria	-	10^6
Endotoxins	4,655	3,522	Coagulase (-) Staphylococci	10^5	10^6
			Enterococci	-	10^6
Seedorf and Hartung (1999):			Alpha-hemolytic Streptococci	10^5	10^6
in CFU/ml:			*Weeksella virosa*	-	10^6
Total bacteria	843,000		*Alcaligenes* sp.	-	10^6
Fungi 25 °C	1,500		*Aspergillus* sp.	-	10^2
in EU/ml:			Other moulds	-	10^2
Endotoxins	242		Yeasts	-	10^2

The high amounts of aerosols in the BWAPS can lead to the assumption that particles and even airborne microorganisms may be transported into the ambient air via the clean gas. This can partly be confirmed by practical efficiency measurements as shown in Figure 4. In opposite to dust particles there were no consistent reductions for bacteria and fungi, which have shown relative cumulations in the clean gas between 4 % and nearly 757 %.

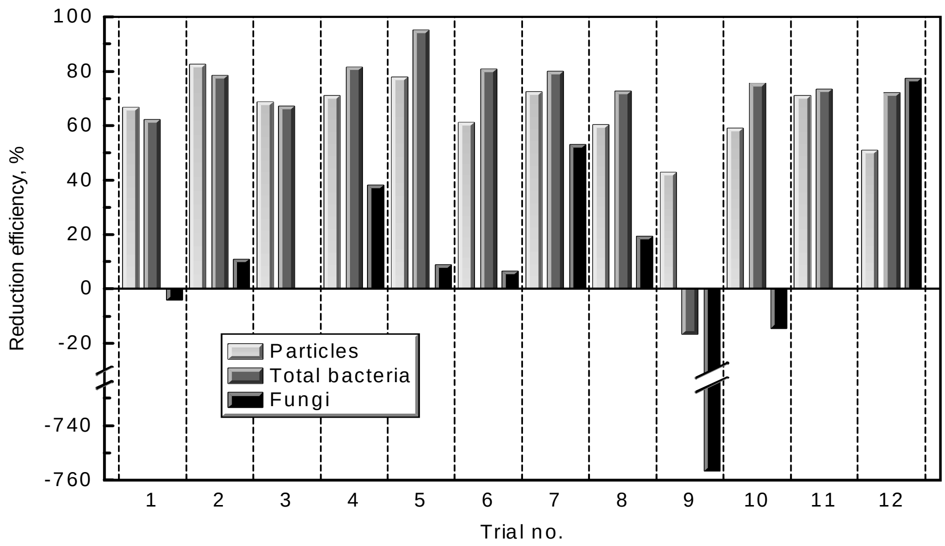

Fig. 4: Reduction efficiency and enrichment effects of a biofilter.

CONCLUSIONS

- Well operated BWAPS are able to reduce odour, ammonia or dust up to 70 %.
- A cascade-like combination of different component-specific reduction techniques can reach 90 % reduction efficiencies for livestock-related airborne pollutants.
- The high number and large variety of microorganisms and their compounds in water and in the air of BWAPS may cause health hazards for the staff and for the environment.
- It is unclear if enrichments in clean gases are caused by primary (livestock air) or secondary (BWAPS-related) emissions; new technical improvements may necessary to avoid emissions.
- There is a need for regular control measurements, sufficient and frequent maintenance schemes and a better training of farmers how to operate the systems to guarantee long-term operation of BWAPS and low hygienic and environmental risks.

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