Air scrubbers

Background

Air scrubbers are an air-purification system that removes particulate matter and/or other gaseous pollutants from the air of a building before being released to the atmosphere. They are used in many industrial facilities to reduce atmospheric pollutant concentrations and can also be used for livestock buildings that are not naturally ventilated. This technology mainly applies to pig and poultry facilities that have forced ventilation, i.e. do not rely on natural ventilation to remove stale air. Most ruminant buildings are naturally ventilated, with fresh air coming in from the sides and out at the ridge via the stack effect.

For scrubbers to be effective all the air from the building must be forced through the scrubber and hence naturally ventilated buildings are not suitable for this system. Even for buildings that are force ventilated there is considerable cost associated with collecting all the 'stale air' and directing it through a scrubber before release to the atmosphere, (irrespective of whether an air scrubber is part of a newbuild or retrofitted). Hence, they are not often employed in pig and poultry facilities unless government policy requires it.

Air scrubbers can be either classed as biological, chemical or a combination of both, depending on the reasons for installation and problem(s) to be addressed.

Atmospheric pollutants from agricultural activities such as particulate matter (PM), ammonia (NH_3), hydrogen sulphide (H_2S) and volatile organic carbon (VOC) have significant influences upon the atmospheric environment and the health of animals and close residents. They can also pose a risk to the health of the animal themselves and farm staff (Guo et. al., 2022). Common, fast-growing species adapted to high nutrient availability thrive in a nitrogen-rich environment and out-compete species which are more sensitive to ammonia/nitrogen deposition. Ammonia pollution also impacts species composition through soil acidification, direct toxic damage to leaves and by altering the susceptibility of plants to frost, drought and pathogens (including insect pests and invasive species). At its most serious, if changes in species composition and extinctions are large, it may be that remaining vegetation and other species no longer fit the criteria for that habitat type, and certain sensitive and iconic habitats may be lost, Guthrie et.al., (2018). Many protected sites in NI have nitrogen deposition rates that exceed their critical load, (DAERA Draft Ammonia Strategy Consultation). DAERA have a target to reduces ammonia emissions from agriculture by 30% (2030) compared to 2020 levels. Part of their plan is the uptake of verifiable ammonia reduction technology in livestock housing, hence this investigation into air scrubbers.

Air scrubbers can be referred to as end of pipe solutions and have been developed mainly with ammonia capture in mild, but in recent times combination scrubbers have been developed, (acid and biological) to enhance removal of not just of ammonia, but other contaminants such as particulate matter and odour, Melse et al., (2009).

Ammonia scrubbing technologies are well researched and ready for practical use. However, costs are high and cost reduction options need to be further investigated. The benefits of scrubber applications may be enhanced by development of scrubbers that not only successful remove ammonia but also reduce environmental impact by achieving high odour and particulate matter removal efficiencies, (Melse & Timmerman 2009). By the start of 2009 in the Netherlands there were 880 air scrubbers in operation, mainly at pig houses and mostly chemical scrubbers, (Melse & Timmerman 2009).

From a review of the literature on air scrubbers for agricultural buildings, there are a lot more scientific papers available on biological air scrubbers compared to chemical air scrubbers. This might be because chemical scrubbers usually involve using acids, (often sulphuric acid), while biological air scrubbers are a lot more diverse in terms of the materials used and operation of the system.

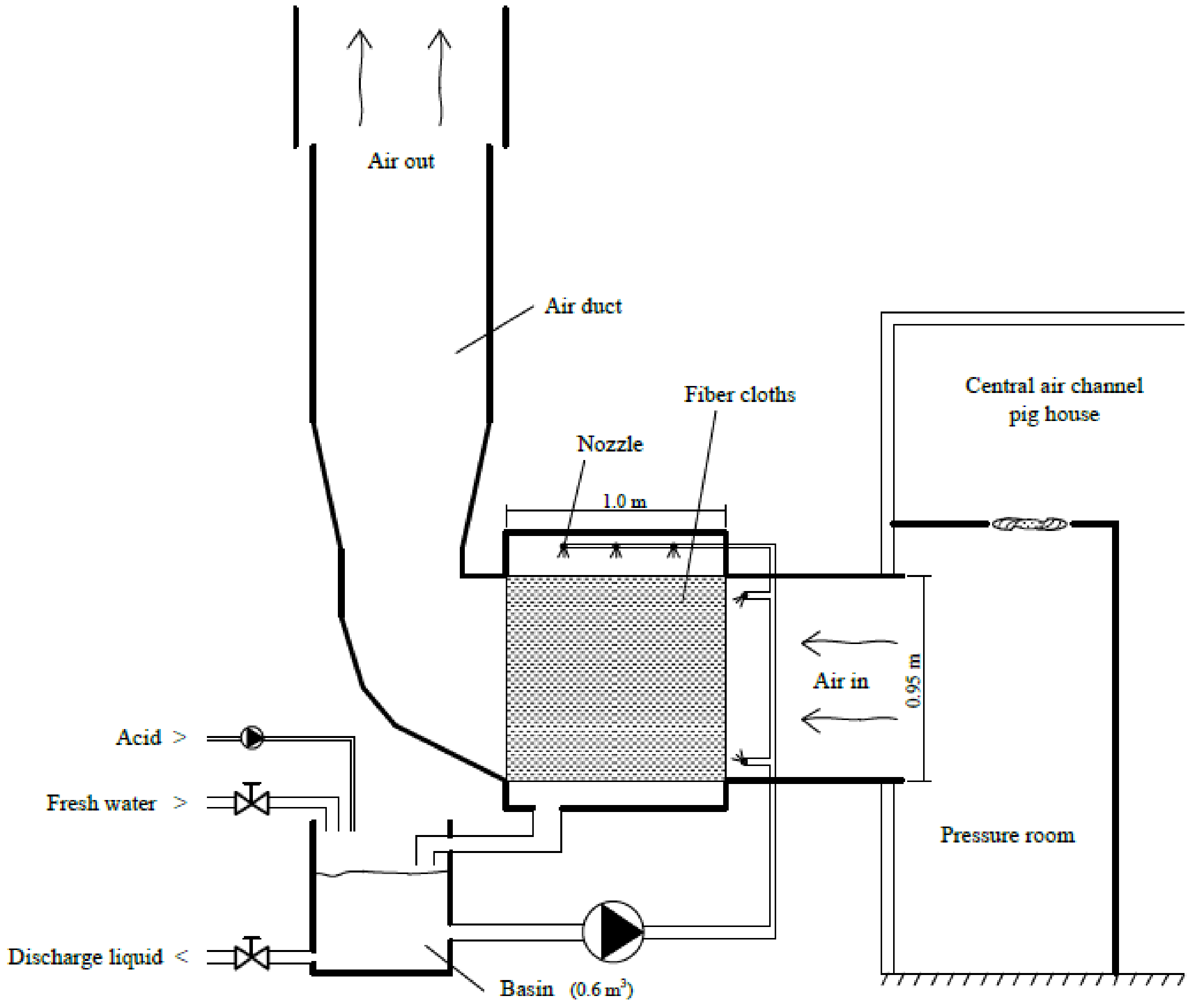
Chemical Air Scrubbers

Acid scrubbers are based on the entrapment of ammonia in acid liquid that is recirculated over a packed-bed and the frequent discharge of the resulting ammonium salt, (Melse & Timmerman 2009). They consist of a packed tower that has been filled with an inert or inorganic material. The packing material usually has a large porosity, or void volume and a large specific area. Water is sprayed on top of the packed bed and consequently wetted. Contaminated air is introduced, either horizontally (crosscurrent) or upwards (counter-current), resulting in intensive contact between air and water, and enabling mass transfer from gas to liquid phase. A fraction of the trickling water is continuously recirculated; another fraction is discharged and replaced by fresh water (Melse & Ogink 2005).

The pH is controlled, usually at a value below 4, by addition of acid to the recirculation water. This shifts the equation below to the right, i.e. NH4+ in solution.

NH_3 (gas) + H_2O (liquid) $\leftrightarrow$ NH_3 (aqueous) + H_2O (liquid) $\leftrightarrow$ NH_4 + (aqueous) + OH− (aqueous)

If sulphuric acid is used, ammonium sulphate $(NH_4)_2SO_4$ solution is produced. The ammonium sulphate concentration is usually controlled at a level of about 150 g/L, which is about 40% of the maximum solubility, otherwise precipitation will start to occur. (In the Netherlands only sulphuric acid is allowed to be used in acid scrubbers, (Melse & Ogink 2005). Removal efficiencies of ammonia can be higher than 90%. Both pH and water discharge rate can be automatically controlled relatively simply with standard equipment. Acid scrubbing can be considered as a stable and reliable measure for NH3 emission reduction, (Melse & Ogink 2005). Odour removal is relatively low with acid scrubbers, but somewhat higher with biological methods, (Melse 2009).



Schematic of an acid scrubber

A commercial company (Lely, Netherlands) have developed an acid scrubber for dairy cattle houses. Stale air is pulled down through holes in a bespoke passageway floor and then through a typical acid scrubber. The floor has stainless steel inserts with holes to allow urine to drain through, whilst the manure is collected by a robot and emptied into a separate tank. Water is sprayed by the robot as it collects faeces, which helps to keep the floor cleaner and reduces ammonia emissions. There are no scientific papers available on this technology yet, but the combination of urine separation and acid scrubbing should significantly reduce ammonia emissions from this system, whilst providing a liquid fertiliser, thus reducing the need to purchase inorganic fertiliser.

Biological Air Scrubbers

The use of biological methods for the treatment of polluted and odorous air has been available for over 60 years, Rybarczyk et. al., (2019). In general, the process of biofiltration consists in the decomposition of gas contaminants by bacteria or other microorganisms inhabiting the porous packing bed of the biofilter, Rybarczyk et. al., (2019). There are three main types of biological air scrubbers: biofilter, bioscrubber and biotrickling filter, although the differences between them are relatively small. They all involve using micro-organisms that degrade/transform gaseous contaminants, thus purifying the air before release, (Wua et. al., (2019).

In general, the process of biofiltration consists of the decomposition of gas contaminants by bacteria or other microorganisms inhabiting the porous packing bed of the biofilter. Pollutants adsorbed on and absorbed by the biofilm undergo biodegradation. Finally, the cleaned gas leaves the biofilter. The general mechanism of biofiltration is similar for all given bioreactor types, however they differ in the construction as well as possible applications. The first step of biofiltration includes a mass transfer of the given compounds from the gas to the moist bed material or to the liquid phase. Then the compounds undergo biodegradation within the so-called biofilm layer formed at the surface of the packing elements, Rybarczyk et. al., (2019).

Biofilters

Biofilters are termed fixed-bed bioreactors, in which active microorganisms are immobilized. The air is humified in one chamber before entering another chamber containing the biofilter, (Rybarczyk et. al., 2019). The pollutant gases flow through the porous bed material and diffuse into the biofilm formed by the microflora where biological oxidation of the undesired compounds takes place. The pollutant is transferred from the gas phase to the biofilm by both adsorption and absorption. Diffusion and aerobic biodegradations are the main steps that simultaneously take place into the biofilm. The filter material is usually organic: wood, peat, charcoal, compost and activated carbon are common packing materials and sometimes mixtures of these. Inorganic materials may be used due to their regular and stable structure and lack of biological breakdown but require inoculation. Activated sludge is often used for this purpose, (Barbusinski, et. al., 2017). For ammonia removal the biofilter converts this to nitrate, but denitrification is also a possibility is not enough oxygen is available. The nitrate is removed in the wastewater normally to a slurry tank. Biofilters are lower cost than other types of air scrubber and are suitable for lower concentration gases. Disadvantages include difficulties in moisture and pH control, low efficiency of the treatment of high-concentration pollutants, deterioration of the bed material leading to the need for its periodic replacement and possible clogging, (Barbusinski, et. al., 2017). For the proper performance of a biofilter, parameters including packing material pH, inoculum, bulk density and inlet gas composition play a key role in achieving better performance, (Morral et. al., 2021).

The performance of a biofilter is usually described by three basic parameters: removal efficiency, elimination capacity and inlet loading rate. Mass transfer is only possible if the gas is in contact with the liquid for some duration of time. Usually, this time is expressed as the empty bed air residence time (EBRT), which can be calculated by dividing the reactor volume (m3) by the airflow rate (m3/hour), (Melse et. al., 2005).

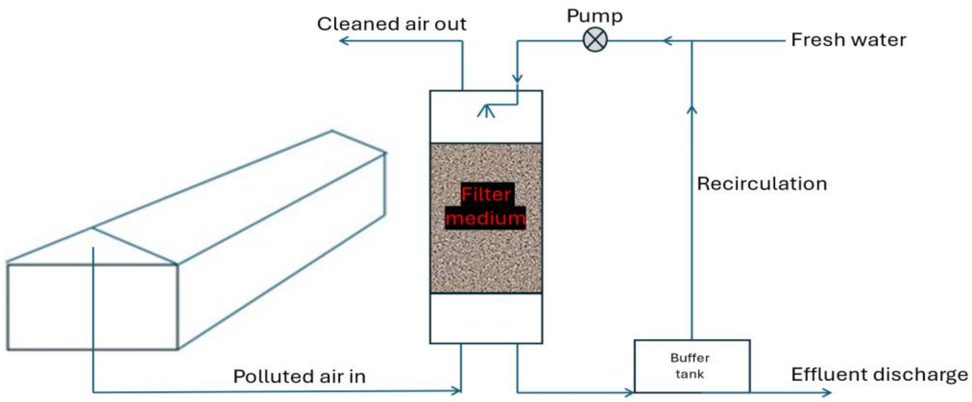
Bio scrubbers

The principle of bio scrubber operation is based on two main stages that usually take place in separate devices. In the first tank, ‘the absorber’, gaseous pollutants are absorbed into the liquid phase, which then goes to the second tank, the bioreactor. The bioreactor is filled with an aqueous suspension of microorganisms in which biodegradation of pollutants takes place. The liquid circulates through tanks supplied with air, nutrients for bacteria and pH adjusting solutions, while the excess of activated sludge is drained outside the system. Bio scrubbers are successfully used to remove odours, in particular H2S, NH3, and organic compounds with sulphur. However, due to their acidic nature, these substances cause a significant drop in pH, which may result in acidification of the medium circulating in the installation and a decrease in the efficiency of gas treatment, (Barbusinsk et. al., 20210

Biotrickling Filter

With a biotrickling filter the aqueous phase is trickled over the filter bed, which is usually made of some synthetic or natural inert material. The packing material needs a large specific surface area, high porosity, high chemical stability and structural strength, low weight, suitable surface for bacterial attachment and growth, and low cost. The aqueous phase will normally be water containing nutrients to enable growth of the microflora on the filter bed. The aqueous phase is recharged and recirculated usually continuously. The polluted air often flows counter current to the aqueous phase, (Barbusinski, et. al., 2017). Biotrickling filters show high abatement performance for the treatment of H2S and other water-soluble compounds. e.g. ammonia, hence, their suitability for livestock houses. Biotrickling filters have been proven to be an efficient method for the removal of odorous compounds from air streams and this is an added benefit for livestock houses (Rybarczyk et. al., 2019).

Ammonium is removed by bacterial conversion to nitrite (or nitrous acid) and nitrate (or nitric acid), similar to a biofilter. The bacterial population, or biomass, in the system grows partly as a film on the packing material and is partly suspended in the water that is being recirculated. The accumulated nitrite and nitrate are removed with the discharge water, (Melse et. al., 2009). Water is sprayed on top of the packed bed and consequently wetted. Contaminated air is introduced, either horizontally (crosscurrent) or upwards (counter-current), resulting in intensive contact between air and water, and enabling mass transfer from gas to liquid phase. A fraction of the trickling water is continuously recirculated; another fraction is discharged and replaced by fresh water. For a given compound, the mass transfer rate from gas to liquid phase is determined by the concentration gradient, the size of the contact area between gas and water phase, and the contact time of gas phase and liquid phase.



Schematic of a biological air scrubber

Combination Scrubbers

More than one type of scrubber maybe installed at a livestock facility. Chemical scrubbers are generally more efficient at removing ammonia, whilst biological filters are more efficient at removing odours and particulate matter, but neither are good at removing microorganisms that may spread disease, (Aarnink et. al., 2011). Research has been undertaken in the Netherlands on multi-stage scrubbers (Melse et. al., 2015). They concluded that this combination (acid and biological) provides an attractive option for large scale livestock operations to remain in operation in areas with nearby located residential areas and sensitive ecosystems. A survey carried out in The Netherlands in 2018 (Melse et. al., 2018) found that acid and bio-trickling filters were operating close to assigned values, but combination filters were not reaching set standards, but the reasons for this were not determined.

Summary/comments

Both chemical and biological air filtration systems are well proven technologies that are used in a wide range of industries for the removal of chemicals/odours before release to the atmosphere. The type and configuration employed depends on the problem to be solved. They are seldom/never used on cattle houses that are mostly naturally ventilated and not often in pig/poultry houses unless mandated, due to the capital and running costs. However, their use in livestock houses can reduce ammonia, odours and particulate matter emissions. Air scrubbers have only been used to a very limited extent in poultry housing due to dust levels, which can clog filters. A dust filter may be employed before a single or combination air scrubber in some cases.

The adoption of the scrubbers involves an increase of the cost for pig rearing due to the required investment as well as to the operativity costs. In this context, in the absence of an additional remuneration from the agri-food industry and/or of specific subsidy framework the adoption of scrubbers will be limited and consequently, also the related environmental benefits will be negligible, (Ruiz-Colmenero et. al., 2024).

Literature Cited

A review of biotechnologies for the abatement of ammonia emissions, Eloi Morral, David Gabriel, Antonio D. Dorado, Xavier Gamisans. Chemosphere 273 (2021) 128606

Air scrubbing techniques for ammonia and odor reduction at livestock operations: review of on-farm research in The Netherlands, R. W. Melse, N. W. M. Ogink. Transactions of the ASAE Vol. 48(6): 2303−2313

Air treatment techniques for abatement of emissions from intensive livestock production (R Melse PhD Thesis Wageningen University 2009)

Air Treatment Techniques for Abatement of Emissions from Intensive Livestock Production, Roland W. Melse, Nico W.M. Ogink and Wim H. Rulkens. The Open Agriculture Journal, 2009, 3, 6-12

Air treatment technologies in pig farms. Life cycle assessment of dry and wet scrubbers in Northern Italy and Northeastern Spain, Marta Ruiz-Colmenero, Michele Costantini, Ariadna Ballega, Michele Zoli, Miquel Andon´, Miriam Cerrillo, Emma Fabrega, August Bonmatí, Marcella Guarino, Jacopo Bacenetti. Science of the Total Environment 922 (2024) 171197

Biological methods for odor treatment: A review. Krzysztof Barbusinski, Katarzyna Kalemba, Damian Kasperczyk, Krzysztof Urbaniec, Violetta Kozik. Journal of Cleaner Production 152 (2017) 223-241

Draft Ammonia Strategy Consultation http://www.daera-ni.gov.uk/consultations

Recent progress and perspectives in biotrickling filters for VOCs and odorous gases treatment. Hao Wua, Huayu Yana, Yue Quana, Huazhang Zhaob, Nanzhe Jianga, Chengri Yina. Journal of Environmental Management Volume 222, 15 September 2018, Pages 409-419

Mitigation strategies of air pollutants for mechanical ventilated livestock and poultry housing—A review. Atmosphere Guo, L., Zhao, B., Jia, Y., He, F. and Chen, W., 2022., 13(3), p.452.

Removal of Odors (Mainly H_2S and NH_3) Using Biological Treatment Methods, Krzysztof Barbusinski, Anita Parzentna-Gabor, and Damian Kasperczyk. Clean Technol. 2021, 3, 138–155

SCRUBBER CAPABILITIES TO REMOVE AIRBORNE MICROORGANISMS AND OTHER AERIAL POLLUTANTS FROM THE EXHAUST AIR OF ANIMAL HOUSES, A. J. A. Aarnink, W. J. M. Landman, R. W. Melse, Y. Zhao, J. P. M. Ploegaert, T. T. T. Huynh. Transactions of the ASABE Vol. 54(5): 1921-1930 (2011)

Survey Of Air Scrubber Performance At Pig Farms In Practice: Odour And Ammonia Removal Still A Challenge, Roland W. Melse, G.M. Nijeboer, Nico W.M. Ogink. Abstract for the AgEng Conference 2018: New Engineering concepts for a valued agriculture - Wageningen, Netherlands, 8 July 2018 - 12 July 2018

Sustainable intensive livestock production demands manure and exhaust air treatment technologies, Roland W. Melse, Maikel Timmerman. Bioresource Technology 100 (2009) 5506–5511

The impact of ammonia emissions from agriculture on biodiversity, Susan Guthrie, Sarah Giles, Fay Dunkerley, Hadeel Tabaqchali, Amelia Harshfield, Becky Ioppolo, Catriona Manville, (2018) www.rand.org/t/RR2695

Treatment of malodorous air in biotrickling filters: A review. Piotr Rybarczyk, Bartosz Szulczyński, Jacek Gębicki, Jan Hupka. Biochemical Engineering Journal Volume 141, 15 January 2019, Pages 146-162