

DEVELOPMENTS IN ODOUR CONTROL FOR THE WASTEWATER INDUSTRY

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Abstract

It has never been an easy task predicting odour nuisance from wastewater treatment facilities nor treating odours effectively with predictable costs. With the availability of more objective tools to quantify odours and the use of more reliable and more cost effective treatment methods, odour nuisance problems from wastewater facilities can now be controlled more simply and predictably, using advanced biological systems. It can make life much easier for plant managers and operators.

Introduction

In climates like Australia odour problems are exacerbated by elevated temperatures. The often relatively flat coastal terrain with high population densities and long rising sewer mains leads to a relatively high risk of odour problems. The sandy soil which is often present also increases the risks of odour problems due to the intrusion of sulphate-rich seawater. (Sharma *et al*, 2008).

Wastewater treatment plants built many years ago outside of residential areas, are now often hemmed in by residential developments. Wastewater collection systems have often been extended over the years resulting in greater odour emissions as a result of the septic conditions created in these extended sewage collection systems. Municipalities and water corporations are constantly searching for cost efficient and community friendly methods of dealing with odours emitted from wastewater collection systems and wastewater treatment plants.

Traditionally, odour control methods, while fairly effective, involved chemical addition to the sewer, chemical scrubbers and activated carbon filtration which come with high operating costs and require operator attention. Preferred odour control methods are chemical free, with low predictable operation costs, minimal maintenance and easy to operate.

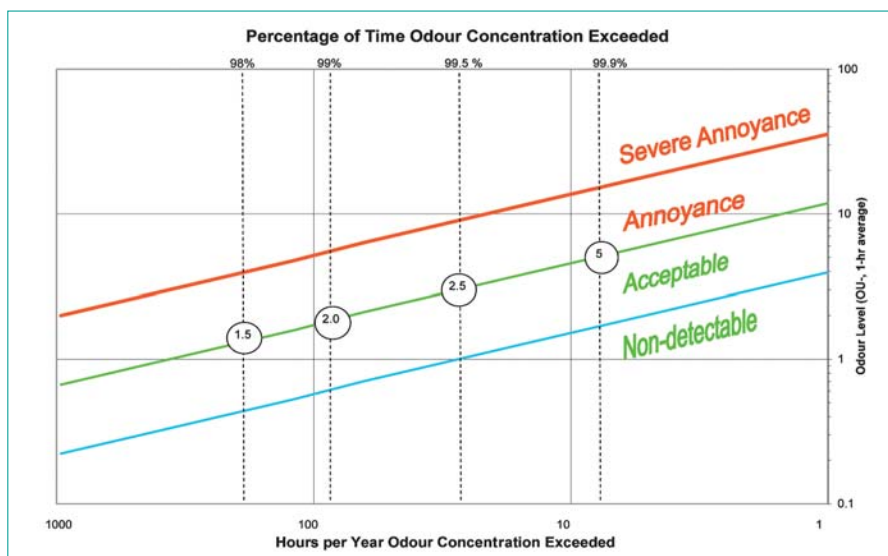


Figure 1. Acceptable odour concentrations from wastewater facilities in relation to the time of exposure (Wallis and Cadee, 2008).

Developments in Odour Management

Odour management at wastewater collection and treatment facilities used to be largely reactive responding to complaints from people living near the facility. Solving the odour nuisance was not easy, because of the lack of objective useful methods to quantify the problem. This has changed over the recent years as many countries have adopted a practice of dealing with odours from sewage treatment works based on the prediction of odour concentrations using modelling with validation against odour complaints. Odour impact risks analysis is now commonly performed and is often required prior to building new or upgrading existing facilities.

Predicting odour nuisance is not always an easy task. Just because an odour is detectable does not automatically mean it may be classified as a nuisance. Although odour nuisance can be characterised in

Reliability is the key to success in odour control management.

many ways, the most commonly used measure is odour concentration. The odour concentration is expressed in odour units (ou), which represents the number of times that the odorous air needs to be diluted with odour free air so that it is just at the threshold of detection by a panel of trained odour assessors under conditions set by the AS/NS 4323.3, which is based on European GEN methodology.

The acceptable level of odour concentration by a receptor is dependent on the character of the odour, but always related to the time of exposure to the odour. The acceptable level of odours typical from wastewater facilities can be expected to be close to those proposed by Wallis and Cadee (2008) as shown in Figure 1. Fewer hours of exposure will increase the acceptable levels of the odour.

Risk analysis including predicting odour concentrations is now usually part of an odour management plan for the sewage treatment facility design and urban planning. As fewer hours of exposure will decrease odour nuisance, a more reliable and efficient odour treatment facility will

increase the acceptable odour concentration off-site.

Developments in Odour Treatment

Containment of the odours is important in preventing unwanted odour emissions. Many types of covers for the different processes at the wastewater treatment facility have been improved over the last ten years. This can reduce the amount of foul air extraction required to ensure negative pressure under covers and prevent or reduce the volume of fugitive odour releases from these covered sources. Maintaining negative pressure where access for inspection and maintenance is required will be more difficult to achieve and thus higher ventilation rates must be adopted for these.

Different technologies for odour control are used; among the most common are chemical-physical methods like chemical dosing or scrubbing, adsorption using activated carbon and biological methods. With uncertain energy prices, more advanced biological systems are of increased interest due to their low operating costs and their improved reliability. Hardly any resources are required for operation and no waste is normally generated, which makes biological air treatment usually a 'green' technology with a lower carbon footprint.

Developments in Biological Odour Treatment

Biological systems are increasingly applied to solve problems of polluted air emissions in different industries. Over recent years, much progress has been made in areas such as microbiology, process modelling, reactor design and reactor-operation. Experiences with biological odour control at wastewater facilities ranging from hot climate condition like Australia and the Middle East to colder climate conditions like North Europe and Canada have all led to increases in both efficiency and reliability.

Biological waste gas treatment systems convert a mixture of pollutants from the air into water, carbon dioxide and salts. Micro-organisms, primarily bacteria, are the catalyst of this process. The overall process in a system can be divided in two phases: the mass transfer of the pollutants from the foul air to the micro-organisms, and the biological degradation of the pollutants (see Figure 2). The combination of different physical, chemical and biological mechanisms

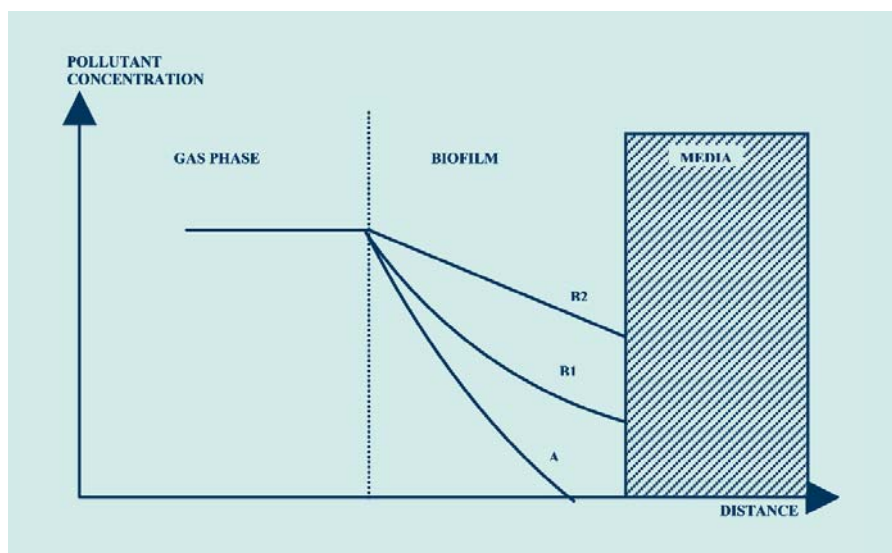


Figure 2. Pollutant concentration profile in biological odour treatment system for a compound that is mass transfer limited (A) and biological reaction limited (B1 and B2). The biological reaction limited can be dependent on the pollutant concentration (zero order kinetics; B1) or independent on the pollutant concentration (first order kinetics; B2).

results in a relatively complex system. Fundamental parameters including mass transfer, absorption of the different pollutants and degradation kinetics in the biofilm, as well as airflow and water distribution are often difficult to quantify. Much progress has been made in understanding the fundamental aspects, which are necessary for design and operations. Still much of the current design work, on both sizing and operations, is based on empirical experience. Models have been greatly improved but are still not always applicable, especially for the treatment of compound mixtures and varying concentrations.

Various reactor configurations have been developed for different applications. The different biological techniques are traditionally classified as biofilters, biotrickling filters and bioscrubbers. In the wastewater industry, biotrickling filter type systems are now the most common, but are often also referred to as bioscrubbers. The conventional biofilters using organic or partly organic media are applied less frequently as they face important design limitations and operating stability problems. The air stream from, for example, wastewater normally contains hydrogen sulphide, which is oxidised to sulphuric acid in a biofilter system. Sulphuric acid accumulates in the media as it is difficult to wash with water, reducing the overall odour removal efficiencies over time. Also, the air streams are not always completely saturated with water, which leads to partial drying out of the media, especially in the inlet, (usually bottom),

part of the biofilter. Moisture conditions are critical in a biofilter and a drop in moisture as result of uneven irrigation or no prehumidification will result in a reduction of odour removal efficiency. Over-irrigation can also result in premature media decomposition and increased in backpressure and power use.

The design and operational limitations of conventional biofilters including the requirement of media replacement are solved with the development of more advanced biological air treatment systems. In the more advanced biological odour treatment reactors the media change-out or cleaning is no longer required, since inert preferable structured support material for the micro-organisms is used as well as the control of conditions for the biological process is improved. Although the more advanced systems require higher investment cost, the operational costs are greatly reduced, since up to 40% of the operational cost of a conventional biological system is typically related to the media change-out.

The most important process parameters for biological odour control in the wastewater industry are a wet environment and optimal conditions (e.g. pH, nutrients) for the different micro-organisms. The inlet odorous airstream provides an ongoing source for oxygen and energy (the odorous compounds) for the biological process.

Odour control in the wastewater industry is specific for the following reasons:

- The air contains a mixture of compounds, which requires a mix of different micro-organisms for its removal in order to achieve high efficiencies or low outlet concentrations.
- Reliability is important to minimise operator interference as in many situations the odour treatment equipment has to operate unstaffed, for example at lift stations and small wastewater treatment facilities.

Odours from Wastewater are a Mixture of Compounds

Odorous air streams from wastewater processes contain a mixture of many compounds. These various compounds usually have very different chemical properties as can be seen from, for example, their water solubility and their biodegradability. To degrade all odorous compounds an optimal mix of micro-organisms is required. Micro-organisms differ from each other in their capacities to obtain their energy, carbon and nutrients. Micro-organisms also differ in their ability to form a good biofilm structure, their growth-rate, their affinity for compounds, their degradation capacity, and their nutrient requirements. Unfortunately the optimal environmental conditions for the micro-organisms also differ. Therefore due to the many different compounds in the air stream, a mix of micro-organisms is required and different environmental conditions are preferred in the biological odour treatment system.

When an air stream contains multiple compounds, it can be expected that the removal of many of the compounds is affected by the presence of other compounds. In the situation that a bioreactor system is removing two or more compounds, the metabolic activity in a micro-organism may involve the

Table 1. Examples of volatile reduced sulphur compounds (WEF, 2004).

Pollutant	Formula	Molecular Weight	Odour Threshold (ppb _v)
Hydrogensulphide	H-S-H	34	0.47
Methylmercaptan	CH ₃ -SH	48	1.1
Dimethylsulphide	CH ₃ -S-CH ₃	62	0.1
Ethylmercaptan	CH ₃ -CH ₂ -SH	62	0.19
Allylmercaptan	CH ₂ =CH-CH ₂ -SH	74	0.05
Propylmercaptan	CH ₃ -CH ₂ -CH ₂ -SH	76	0.075
Crotylmercaptan	CH ₃ -CH=CH-CH ₂ -SH	90	0.029
Dimethyldisulphide	CH ₃ -S-S-CH ₃	94	1
Amylmercaptan	CH ₃ -(CH ₂) ₃ -CH ₂ -SH	104	0.3
Benzylmercaptan	C ₆ H ₅ -CH ₂ -SH	124	0.19

mechanism of induction, inhibition and sometimes co-metabolism. Induction refers here to the process that initiates the production of enzymes that catalyse the biodegradation in the cell. Inhibition involves the toxicity effect of certain compounds on the metabolic activity of the micro-organisms and co-metabolism is the (partial) conversion of certain compounds by enzymes that are induced by other compounds. The mechanism for micro-organisms to ensure that the organism uses the more readily catabolizable carbon and energy source is called catabolite repression. One consequence of catabolite repression can be that if more compounds are present at the same time, the metabolism of a certain compound is resumed only after another compound causing catabolite repression is used first (so-called diauxic growth). Therefore it is often a necessity in a biological system that certain compounds are removed first, before other compounds can be removed.

Biological odour treatment reactor at wastewater collection and wastewater treatment plants often deal with many odorous compounds, among them mixtures of volatile reduced sulphur

compounds, like H₂S and mercaptans, which are important because of their very low odour threshold (see Table 1).

Although different micro-organisms are known for the degradation of volatile reduced sulphur compounds, the treatment of an air stream containing mixtures of reduced sulphur compounds remains challenging for two main reasons. Firstly, the energy yielding process of H₂S oxidation is higher and thus preferred over the oxidation of other reduced sulphur compounds. Secondly, the degradation of many of these sulphur compounds is only possible with high efficiencies at neutral pH, while a degradation product from sulphur compounds is sulphuric acid which reduces the pH.

Different types of organisms require different environmental conditions including the absence of easily degradable compounds and are, therefore, preferably separated in different layers of the reactor.

Polishing with, for example, activated carbon is now often applied to obtain low outlet odour concentrations, but is normally not necessary when the biological odour treatment system is designed well. The elimination of activated carbon polishing reduces complexity and the risk of unpredictable operating costs involved with the change-out and the disposal of the activated carbon.

Maintaining Optimal Conditions

The reactor size and shape and the configuration of the internal carrier (media) for the micro-organisms directly influences the removal capacity of the biological system and will impact important design parameters such as mass-transfer rate, bacterial degradation capacity, water holding capacity and pressure loss.

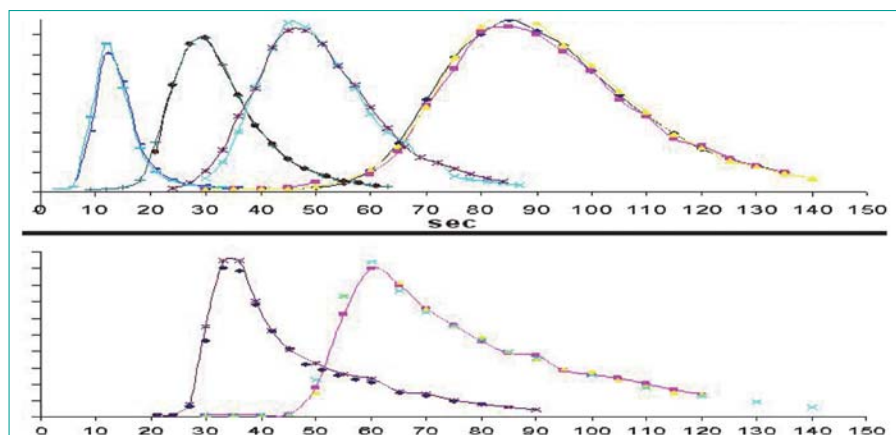


Figure 3a and 3b: Examples of gas distribution in a reactor expressed in seconds of different media at different gas velocities. (Kraakman, 2008).

Often underestimated is the influence of the reactor and media configuration on the air flow characteristics through the biological gas treatment system. When high removal efficiencies are required (>99%), all the air has to be treated effectively. In order to treat the air effectively, all the air needs to stay in the reactor for a minimum period of time to exchange the compounds to the catalysts in the biofilm on the media. An optimum air distribution in the reactor is required and preferably moves the air through the reactor as a plug-flow. Preferential air streams or partial by-passes of the air should be avoided at all times.

In present theoretical models describing the degradation of gas components in biological filters, air flow is described as a plug-flow, but this theory seems to be oversimplified as illustrated in Figure 3a and 3b showing examples of real gas distribution in typical media.

The air flow behaviour has considerable effect on the maximum achievable outlet concentrations and thus overall cleaning efficiency (Kraakman, 2008). A reactor with one layer of randomly packed media is likely to be subject to sub-optimal air distribution through the media after a period of operating time. Pre-engineered structured media can prevent this. Structured media also makes the operation more determined by design rather than chance. The media used should be inert and not subject to blocking, fouling, erosion or corrosion causing, for example, shrinking of the media or preferential airstreams through the media.

The method by which water is added to the reactor is important as water not only prevents the biofilm layer in the biological system from drying out, but also serves as a supplier of nutrients for the micro-organisms in addition to removing the degradation product, sulphuric acid. Water can be re-circulated over the media or can be added to the top of the media and then, after passing through the media, be directly removed from the bottom of the system. Minimising water use in the reactor can have benefits. First, a thinner water film can be maintained on the biofilm layer, which is often preferred to minimise the resistance for mass transfer of the pollutants from the gas phase to the micro-organisms. Secondly the thinner water film on the media results in



A multi-layered biological odour treatment installation treating 126,000 m³/h of odorous air (Cesca *et al*, 2009).

a larger void volume in the media. A larger void volume is better as the pollutant airstream will be in contact with the biofilm longer, resulting in a longer so-called actual residence time. The actual gas residence time is a better design parameter than the often used theoretical empty bed gas residence time (Theoretical EBRT) as it represents the real time in seconds that the air is in contact with the biofilm.

Theoretical EBRT = media volume (m³) / air flow (m³ sec⁻¹) (sec)

Actual RT = media volume (m³) x void fraction (%) / airflow (m³ sec⁻¹) (sec)

Optimising Reliability

Equipment should preferably be simple and reliable to operate. Quantification of the robustness of a biological air purification system would be helpful to designers and operators. Robustness can be defined to reflect the ability of the biological system to deal with fluctuations and operational upsets. Robustness may be quantified by determining the risk of negative effects on the biological system for each possible upset, multiplying by the frequency of the upset, and summing over all possible upsets.

The risk of negative effects on a biological system (R) can be defined as:

$$R = \sum (p \times E)$$

p = the probability of occurrence of an upset

E = the negative effect of the upset

The negative effect of the upset (E) can be expressed as the loss of the removal efficiency (%), the loss of the total removal (kg/day or kg/year), or the impact on the people living near the installation (e.g. the number of occurrences during which the concentration of the emitted air stream exceeded the allowed odour threshold in the neighbourhood).

The microbiological community in a biological treatment system will face fluctuations related to the process upstream as a result of continuous or discontinuous processes, irregularly unplanned shut-downs, planned maintenance shut-downs and diurnal fluctuations. There may also be fluctuations related to the operation of the system, for example, associated with loss of control of power, water or nutrient supply. Examples of quantification of robustness of full-scale biological waste gas treatment systems are illustrated elsewhere (Kraakman, 2003 and 2004).

Microbial responses to stress conditions are interesting and important to quantify. Biological air treatment systems using mixed microbial cultures as inoculum are self-optimising with species becoming dominant that are most competitive under the environmental conditions in the system. Unfortunately this self-optimising adaptation process seems to be relatively slow and is likely to take months or longer. On the other hand, different applications and tests showed that a biological system can deal with spikes.

Experiences also show a biological system can handle very well the diurnal occurring peaks typical for odour emissions from wastewater processes. When temporary reduced removal efficiencies are noticed, it's often the first day after many days of wet weather when the relatively low concentrations reduce the (enzyme) activity of the microorganisms over a couple of days. Recovery to full activity is fast and is normally a matter of minutes or hours to maximum of one day.

It's important that the robustness is quantified and the risks are understood,

so that extra measures can be taken if necessary to reduce the risks to obtain an odour treatment system that is predictable in operational costs and is operator friendly.

Conclusions

In climates like Australia odour problems are exacerbated by the high temperatures and the relatively flat and densely populated areas along the coast.

Odour management at wastewater collection and treatment facilities use to be mainly based on reacting to odour complaints from people living in residences nearby the odorous facilities. Solving the odour problem was not easy, because of a lack of useful objective methods. This has changed over the recent years as now the practice used for dealing with odours from sewage treatment works is based on the prediction of odours using modelling with validation against odour complaints.

Odour control methods are preferred that are chemical free, have low and predictable operational costs, relatively maintenance free and easy to operate. The development of more advanced biological systems solved the design and operational limitations with conventional biological odour treatment systems including the requirement of internal media replacement. In the more advanced biological odour treatment systems the media change-out or cleaning is no longer required and the reliability greatly improved.

With the use of more objective tools to quantify odours combined with the use of more reliable cost effective treatment methods, odour emissions from wastewater facilities can now be controlled more simply and predictably.

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