ODOUR CONTROL DEVICES – SELECTION, DESIGN AND APPLICATION

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ABSTRACT

Wastewater odours can cause offence and disruption to communities and property owners in close proximity to wastewater assets. This in turn can cause reputational risk to asset owners and vexatious technical issues to wastewater network operators and designers.

This paper investigates a range of odour control devices as a tool to asset owners and designers alike for the purposes of controlling and mitigating wastewater odours. The means of appropriate technical selection of devices is considered along with a commentary on common misconceptions impacting device selection. The sizing of devices is considered, along with guidelines for the appropriate sizing for both effective odour treatment and optimised whole of life costs.

A consideration of wider wastewater network issues is undertaken and a methodology for effectively integrating odour control devices into existing networks to facilitate effective odour solutions is given. The principles of Integrated Odour Management are highlighted and used to demonstrate effective methods of reducing hydrogen sulphide production and air flow management to in turn improve the effectiveness of odour treatment, and reduce the operating costs of odour devices employed on troublesome wastewater networks.

KEYWORDS

Wastewater, Odour, Odour Control, Hydrogen Sulphide, Sewer Gases, Carbon Filter, Bark Bed, Bio Filter, Biological Scrubbers

1   INTRODUCTION

Wastewater collection systems can be a source of wastewater odours that lead to complaints from members of the public and nearby property owners. While the technical causes and environmental conditions for the production of sewer gases and odours are widely varied, it is a common solution for asset owners to treat wastewater odours at points of discharge from the collection system. A wide range of odour treatment devices, materials and technologies confront asset owners when tasked with identifying a solution to an odour issue.

While a wide range of variables exist for the optimum selection of odour treatment devices, some consistent themes can be established and used to provide guidance in the selection of suitable solutions. These general themes can be summarised as:
1. Cost – including initial capital cost and whole of life cost;
2. Effectiveness and reliability;
3. Maintenance requirements;
4. Air flow rates; and
5. Sulphide loading rates.

This paper will investigate common odour treatment devices and summarises the attributes of each. In addition methodologies for reducing sulphide loading rates will be discussed.

2   RANGE OF DEVICES

Odour control devices in common use in New Zealand can be divided into two broad groupings based on the media used, and an additional two groupings based on the mode of operation.

The two broad groupings of media use are:

1. Activated carbon, and;
2. Biological based media, often also referred to as bark beds or bio-filters.

The two primary modes of operation are passive ventilated units or active ventilated units. Passive ventilated units rely on naturally occurring air flows or differential pressures within wastewater collection systems or pump stations to drive odorous air through the treatment device. Active ventilated units rely on fan forced air flows.

Each type of media and mode of operation have technically appropriate applications that are dependent on the specific circumstances and requirements of each application. Specific circumstances vary widely. A summary of relevant media and attributes is set out below.

3   CARBON BASED MEDIA TREATMENT DEVICES

Carbon based media refers to activated carbon. There is a wide range of forms of activated carbon, including over 1,000 patents for the manufacture of different forms of it. Activated carbon can be manufactured from a variety of carbonaceous materials including wood, lignin, nutshells, coal, lignite, peat, bagasse, sawdust and petroleum residues[1]. Having selected a carbonaceous material that is basically porous, three basic steps are required in the manufacture:

1. Dehydration to drive out excess water;
2. Carbonisation to convert organic material to elemental carbon;
3. Activation to selectively enlarge pores in the carbonised material.

Steam activated carbon manufactured from high quality low ash anthracite coal is a common form of carbon used for odour treatment in New Zealand. The coal is ground into a powder and extruded into cylindrical particles and then carbonated at high temperatures and activated with steam at around 900 degrees C. The manufacturing process imparts key physical properties which are relevant to the performance of the carbon in odour treatment devices. These are:

1. Pore structure and pore size – critical for the physical adsorption of various sewer gases and organic vapours;
2. Mechanical strength – for durability and ease of transport and handling;
3. Air flow back pressure – imparting a low bed resistance to air flow from an open bulk bed structure.

3.1.1   PORE SIZE & AFFINITY FOR ADSORPTION OF ORGANIC VAPOURS

Carbon filters remove constituent sewer odours via two mechanisms. These are physical adsorption of the compounds to the surface of the media, and chemisorption of compounds to chemicals impregnated into the media. Chemically impregnated media will be discussed further below.

Pore size and pore structure are critical to the effective removal of various odour compounds. Environmental conditions also have a significant influence over the performance of various carbon compounds. Humidity and moisture are of critical importance.

To enable adsorption of odour compounds to the carbon, the pore size needs to be sufficiently large enough to contain the odour molecule, but also small enough to retain the odour molecule, and to increase the relative surface area available to adsorb odour molecules.

Physical adsorption relies on weak covalent bonds between the odour molecule and the substrate. Once the substrate or carbon reaches saturation, or environmental conditions change such as temperature, the odour molecules can be released again by the carbon.

Humidity and moisture have a key influence over the effectiveness of adsorption. If the carbon is wet, the pores are filled with water and thus block the pores meaning they are not available to adsorb the odour molecules. Care must be taken in the design of carbon filters to manage humidity and moisture to ensure the carbon does not become 'wet' and that the pores remain available for physical adsorption of odour molecules.

As sewer air is generally very high in humidity or is fully saturated, the management of condensation in carbon filter devices is a key design element.

3.1.2   EXPANDED ALUMINA

Expanded alumina is an odour treatment substrate that has the same modes of operation as activated carbon. It can be considered similar to activated carbon in a number of respects. Expanded alumina is commercially available for the treatment of sewer odours. It is in the form of small spherical balls of a porous structure which impart the physical properties of mechanical strength, low bed resistance for air flow back pressure, and specific pore size to increase surface area and to aid in the physical adsorption of odour molecules.

Expanded alumina is generally combined with chemical impregnations to aid the chemisorption and chemical conversion of odour molecules. Experience has found that the ability of expanded alumina to adsorb organic vapours is limited in comparison to steam activated carbon. The primary mode of odour treatment of expanded alumina is via chemisorption and chemical conversion of odour compounds. Expanded alumina can therefore be highly effective at removing hydrogen sulphide from foul air streams. However, care must be taken to adequately understand the constituent make-up of the foul air stream prior to selecting expanded alumina as a treatment substrate. Due to its low affinity for organic vapours, an odour issue may still persist with the use of expanded alumina, as while the hydrogen sulphide may be effectively removed, organic vapours may still pass through the treatment device and continue to cause objectionable odours, granted that the odours will have an entirely different fragrance to traditional wastewater smells.

3.1.3   CHEMICAL IMPREGNATION

A range of chemicals can be impregnated into the activated carbon to increase the rate of removal and capacity for removal of key odour molecules. The primary constituent of foul sewer air causing offensive odours is hydrogen sulphide gas (H_2S). H_2S gas is therefore focused on with particular relevance to treating wastewater odours, however other gases such as mercaptans, sulphur oxides and other acid gases are relevant and are also targeted by impregnated chemicals.

It should also be noted that various other primary odour compounds are present from a range of heavy industrial processes. These specific odour compounds can be targeted with a range of other chemical impregnations dependent on the specific application. The appropriate technical selection of activated carbon for industrial applications may differ to activated carbons appropriate for municipal wastewater.

Commonly available chemical impregnations for the treatment of sewer gases are:

1. Potassium Iodide;
2. Potassium Hydroxide;
3. Potassium Permanganate.

The H_2S gas is removed by a number of mechanisms. The predominant mechanism for high rate removal of H_2S gas is the chemical conversion of H_2S gas to elemental sulphur, with various impregnated chemicals acting as catalysts. The elemental sulphur is then physically adsorbed to the activated carbon.

A wide range of various proprietary chemically impregnated activated carbons and expanded alumina are commercially available for selection and use in odour treatment devices. Key variances are in the chemicals used, various combinations of chemicals and the concentrations of chemicals.

Activated carbon adsorbs H_2S gas on a mass loading rate. Various carbons and proprietary products can adsorb varying amounts of H_2S gas as measured in weight of H_2S per unit of activated carbon.

Reported results of H_2S gas adsorption are tabled below[2]:

- Potassium Iodide & Potassium Hydroxide impregnated activated carbon: 287g H_2S / litre of carbon
- 8 % Potassium Hydroxide impregnated activated carbon: 140g H_2S / litre of carbon
- Potassium Permanganate impregnated expanded alumina: 112g H_2S / litre of product

The above adsorption capacities are determined under laboratory conditions as per ASTM D6646-03. Conditions in field based carbon filters will vary considerably with a range of other competing odour molecules and sewer gases present and varying environmental conditions such as temperature, humidity and changeable air flow and loading rates. Reliably achievable field base adsorption capacities will be lower than those recorded in a laboratory situation.

CAPACITY OF H_2S GAS REMOVAL

The ability for various carbons to absorb differing amounts of H_2S gas is of key consideration when considering the capital and whole of life costs of carbon filters. A simplistic approach to cost assessment of carbon is to consider the cost per kg of product. This however does not factor into the assessment the amount of H_2S gas that that carbon can adsorb, which is the primary element the asset owner is interested in.

Asset owners are recommended to consider the cost of activated carbon products against the adsorption capacity of H_2S gas. This will reflect the true operating cost of activated carbon. Depending on the actual cost of product available to the asset owner, the product with the lowest cost per kg, or the highest adsorption capacity may not necessarily be the most cost effective product for a certain application.

3.1.4 MULTI-STAGE CARBON FILTERS

In certain applications, the use of multiple stages of carbon should be considered to improve the effectiveness and treatment capacity of a carbon filter. The requirement to include multiple stages of carbon filters is dictated by the range of chemical constituents on the foul air stream, and the concentrations of those constituents.

As stated above, various forms of chemically impregnated carbon can effectively target specific odour compounds in foul air streams, the most readily targeted compound being H_2S gas. It is common for wastewater air streams to contain a number of other constituents in addition to H_2S gas, and depending on the application, it is common for these other constituents to be at concentration levels that cause nuisance odours. It is a possible pitfall to design and install a carbon filter system that effectively removes all H_2S gas, but to continue to receive odour complaints based on nuisance odours of other chemical constituents.

Other chemical constituents are generally by-products of biological decomposition of the wastewater, or present in incoming wastewater streams. Examples are:

- Mercaptans;
- Methyl-sulphides, and;
- Volatile organic compounds.

Mercaptans are used to scent natural gas or LPG. The presence of mercaptans in wastewater odours may lead to reports of smells of natural gas. There are a number of New Zealand based anecdotal cases of members of the public reporting 'gas leaks' resulting in the attendance of emergency services, where the actual cause of the odour was traced back to wastewater networks. One such case is known to have caused considerable disruption including a road closure and evacuation of commercial premises, and was reported in local media.

Methyl-sulphides are by-products of biological decomposition and represent a wide grouping of similar but varying odour compounds. The fragrance of methyl-sulphides can vary depending on the specific constituent odour molecules, however the odour has been previously described as anything ranging from rotting meat, a sweet or pungent smell or very strong aromatic foods such as strong curries.

Volatile organic compounds also vary widely on their particular chemical constituents. Specific compounds measured and recorded in foul wastewater air streams are the range of domestic household cleaner scents, such as lemonien, limien and pinien, i.e. the lemon or pine scents found in dishwashing liquid or toilet cleaner. It is uncommon for the concentrations of these constituents to become detectable over the presence of the primary odour compounds of H_2S gas, methyl-sulphides and mercaptans, however the presence of these compounds should be considered in the design of carbon filters.

A 'straight' activated carbon is more effective at the removal of volatile organics from air streams than chemically impregnated carbons. Using a stage of straight activated carbon at the inlet to a carbon filter will preferentially remove volatile organics from the air stream prior to the air stream passing over the chemically impregnated carbon bed. This improves the removal efficiency and capacity of the overall unit, and reduces the operating cost of the unit. The efficiency and capacity of odour removal is improved as the volatile organics are preferentially adsorbed onto the straight activated carbon. This prevents the volatile organic compounds from passing into the chemically impregnated activated carbon bed in such high concentrations and binding to pore sites that then become unavailable to the primary odour compounds such as H_2S gas. The volatile organics can 'block' pore sites available to H_2S gas compounds, preventing the H_2S gas compounds from undergoing chemisorption or chemical conversion to elemental sulphur by using the impregnated chemicals as catalysts.

It is also noted that straight activated carbon generally costs less than chemically impregnated carbon. This is as the straight carbon requires fewer steps in manufacture and does not contain chemicals with an associated cost. By using straight carbon to preferentially remove volatile organics that will otherwise block pore sites in the activated carbon preventing the removal of H_2S gas, the efficiency of removal and capacity of the chemically impregnated carbon can be increased, and the overall cost of the carbon filter can be reduced.

Therefore it is concluded that multi-stage carbon filters with specific types of carbon to target constituent odour compounds can improve the efficiency and capacity for odour removal of carbon filters, and reduce the operating cost.

3.1.5   RISK OF BED FIRES

There is a theoretical risk of bed fires with the use of chemically impregnated activated carbon. The risk comes about as the carbon is, by definition, highly carbonaceous and can burn readily. The impregnated chemicals are design to catalyse chemical conversion of various odour molecules to other more preferable chemical compounds. In the event a chemical conversion is an exothermic reaction, it is theoretically possible for sufficient heat to be generated within the carbon media to create an ignition and combustion of the carbon. With the situation of a fan forced ventilated unit, a steady air flow can then fan the ignition to fully involve the carbon filter in a significant fire.

Bed fires in carbon filters in municipal wastewater applications are not known to have occurred in New Zealand. There are two primary factors which suggest the risk of bed fires in wastewater odour treatment applications is low. These are:

1.   The comparatively low concentrations of incoming constituent chemical compounds;
2.   The relatively high humidity of foul air extracted from wastewater networks.

The air streams and chemical compounds extracted from wastewater networks are being produced by biological activity; the purity of chemical constituents is mixed at best. It is concluded that the risk of bed fires in municipal wastewater odour treatment applications is low. However designers and asset owners should be aware of the risk and be cognisant of conditions that may lead to that risk increasing when designing and specifying carbon filters. More care should be exercised when considering waste air streams from heavy industrial processes which may have much higher concentrations and purities of specific chemical compounds that may lead to heat generation of exothermic reactions in chemically impregnated carbon.

4   BIOLOGICAL PROCESS BASED TREATMENT DEVICES

The range of types and combinations of media for biological based treatment vary as widely as those available for carbon based treatment devices. The over-arching principles of biological based media are to use a cheap or readily available substrate such as bark or scoria combined with the biological based adsorption of constituent components of foul sewer air.

All biological based processes rely on the bacteria *Thiobacillus* genus. The genus *Thiobacillus* contains Gram-negative polarly flagellated rods that are able to derive their energy from the oxidation of elemental sulphur, sulphides and thiosulphate. *Thiobacillus* can grow chemolithotrophically using reducing sulphur compounds. A few thiobacilli can also grow chemoorganotrophically. Some thiobacilli are obligate acidophiles, meaning they can only grow at acidic pH. The strains of *Thiobacillus* genus with most relevance to wastewater odour treatment are neutrophils, meaning they will grow reliably around neutral pH's. Reference [3].

In short *Thiobacillus* genus is a sulphide eating bacteria that is available to asset owners for the application of odour removal in biological based odour beds. As with any biological process ranging from wastewater treatment to the production of quality home brew or craft beer, biological processes are subject to the vagaries of successfully growing bacteria. This can be an area where science collides with the art of growing things, which can pose a number of additional factors to be considered by the asset owner during the selection, design and operation of odour treatment devices. Factors include the initial seeding and cultivation of appropriate bacteria, commissioning times, and maintaining appropriate moisture and pH for the growth of bacteria.

4.1 BIOLOGICAL MEDIA

A wide range of bed media has been used for biological odour treatment, including compost filters, soil filters and biological towers. The more common types of media are discussed below.

4.1.1 BARK BEDS

Bark beds are possibly the most common form of biological odour treatment and as such the term 'bark bed' is often used as a euphemism for biological odour treatment. A wide range of variations on the specific media of bark beds are in use, however they generally consist of the majority component of bark with various additions of compost to aid biological growth and an element to control pH, such as crushed shells. A typical bark bed media would consist of:

- 65% bark – screened 7 mm to 20 mm;
- 30% screened compost;
- 5% crushed shell.

As for activated carbon, the two critical factors when selecting bark bed media are:

- Mechanical strength – for increased operational life, and resistance to degradation, and;
- Air flow back pressure – imparting a low bed resistance to air flow from an open bulk bed structure.

Additionally, a relevant but less important factor is particle or bark chip size. This has a direct bearing on the total surface area available, but also has an implication on the bed resistance to air flow and the effective lifespan of the bed. As with all biological processes and biological substrates, breakdown of the bark and compost will occur over time, eventually leading to a completely plugged bed matrix leading to excessively high airflow back pressure – meaning the foul sewer air will not be able to pass through the bed and will form fugitive leakage paths.

Starting with smallish bark at 7 to 20 mm gives a good ratio of surface area to volume and acceptable air flow back pressure. However the bed can be expected to break down and plug up sooner than if a larger grade of bark were initially used, such as greater than 40 mm chips. Additionally the ratio of compost used to seed and populate the bed also has a direct bearing on the initial performance of the bed and its expected effective operating life.

Compost obviously leads to the more rapid blocking of air flow within the bed, however it is important for the seeding of the bed and retention of moisture required to sustain reliable bacterial growth.

BARK SIZE, COMPOST RATIO AND OPERATIONAL LIFE
A relationship exists between the size of bark used, the ratio of compost used and the effective operational life of a bark bed. As decomposition of the bed media occurs the bed gradually plugs up until such time as foul sewer air cannot pass through it. The general mode of failure associated with this is the air flow finding fugitive leakage paths, leading to odour complaints, or if the bed is forced ventilated by a fan, the fan working outside of its designed operating range and eventually experiencing mechanical failure.

However, if too large a bark chip is used, the bed will lack appropriate total surface area meaning sufficient contact time cannot be achieved with the foul sewer air, meaning odour treatment will not be effective. Additionally, if insufficient compost is used, or other appropriate steps to seed the bed and encourage bacteria growth are not undertaken, the bed may take an excessive amount of time to commission, or the bed may not establish a suitable micro-flora at all for H_2S gas treatment. A trade off exists between effective operation in the early stages of the bed and the total lifetime effective operation.

COMMISSIONING TIME

A period of time is required to establish a suitable micro-flora of *Thiobacillus* genus. As *Thiobacillus* genus reduces sulphides, a steady stream of sulphides is required to establish the micro-flora. The only practical way to achieve this is to commission the odour bed and let foul sewer air pass through it. Under suitable growth conditions it can be expected that approximately three weeks would be required to establish sufficient micro-flora for effective H_2S gas removal.

Over this commissioning time there is a risk of offensive odours and odour complaints as the bed 'beds down'. While the biological component of this process is unavoidable, there are some mitigating measures available to the asset owner:

1. Seed the bed with a portion of media from an existing established biological bed;
2. Commission the bed in winter.

Most wastewater odour issues have a significant seasonal component to them. The lower ambient temperatures in winter reduce sulphide production in wastewater networks. Additionally, winter rain and inflow and infiltration to wastewater networks that tends to occur in winter can "flush-out" wastewater networks, removing odour problems. When sulphide loading rates are low it is an ideal time to commission odour beds as the risk of odour complaints are low. Additionally, sulphide loading rates will increase gradually as the weather warms up and dries out, meaning that the micro-flora in odour beds can develop gradually over time so that they are most effective over the hot dry summer months when sulphide production and odour complaints are most prevalent.

Commissioning of odour beds or renewing the bark media should be avoided during periods of hot dry weather that coincide with high sulphide loading rates and associated odour complaints.

4.1.2   SCORIA & PUMICE BEDS

To address issues of biological degradation and decomposition of bark, other more inert media substrates can be used. Two leading examples of such a substrate are scoria and pumice. Both substrates are highly porous and possess reasonable mechanical strength to resist compaction and biological degradation. However more effort and care is needed to facilitate the establishment of suitable micro-flora with these substrates than with bark.

Additionally, it is suspected that the rate of physical adsorption of odour molecules to the invert substrates is less than that with bark. While the beds primarily rely on the microbial removal of H_2S gas, the occurrence and importance of physical adsorption in the overall odour treatment process should not be underestimated.

The availability of either scoria or pumice may be restricted to certain regions in New Zealand. The cost of acquiring such substrates for certain regions may be prohibitive. Further consideration should also be given to cultural sensitivities around moving certain media between regions. This is most relevant for crushed shell, which is often not welcome by certain Iwi when it is imported from other tribal areas. The same may apply under certain circumstances for pumice.

4.1.3   DEPTH OF BIOLOGICAL MEDIA BEDS

The key limiting factor in the design of biological media beds is the maximum allowable depth of media. The primary factor governing bed performance and expected effective operational life is air flow back pressure as determined by bed resistivity to air flow. The greater the depth of media, the greater the bed resistivity.

There aren't any strict rules governing bed depth. There is a direct relationship between the attributes of media used and the maximum effective operational depth of a bed. There are a number of obvious benefits to having deeper beds, the primary benefit being the reduction of total required footprint for the bed. This is often a

governing requirement due to constrained space at pump station sites or other wastewater infrastructure locations such as in road reserves or around public amenities such as public parks.

The use of large sized bark chips or the use of scoria and pumice can enable greater bed depths to be achieved. However a factor must be used to adjust the required total volume of the bed to represent the reduction in surface area per volume for large bark chips, or the reduced adsorption ability and biological growth support of inert substrates such as scoria or pumice.

An optimal depth for small bark (7-20 mm) at 65% mixed with 30% screened compost is 500 mm. A maximum depth in the order of 900 mm to 1 m is recommended.

Greater depths with various substrates can be achieved. Scoria beds in the range of 1.5 m to a maximum of 2 m deep are known to exist and work effectively under certain conditions.

4.2 BIOLOGICAL SCRUBBERS

Biological scrubbers, also known as biological trickling filters, are an alternative biological based odour treatment option to be considered. Biological scrubbers consist of a fibreglass or similar inert process vessel containing an inert substrate such as foam blocks or plastic beads. A *Thiobacillus* micro-flora is supported on the inert substrate, which provides the sulphide reducing capacity of the odour treatment in the same manner as for biological based beds. A nutrient stream must be provided to the *Thiobacillus* micro-flora to support healthy growth. This is generally achieved by using simple domestic garden fertilisers in a water stream sprinkled down through the bio-scrubber. Foul air streams are blown up through the scrubber at appropriate residence times to achieve acceptable H_2S gas removal.

The primary advantage of bio-scrubbers is that they can effectively handle very high levels of H_2S gas. Effective treatment of 200 ppm has been reported. The efficiency of removal can be 95%. In certain applications a polishing carbon filter may also be required to prevent nuisance odours from the discharge air stream.

Required footprint is significantly reduced over conventional biological beds. Biological scrubbers are best suited to constant and steady air flows of H_2S gas, which can limit their ability for application in some wastewater network situations with intermittent air flows such as rising main discharge points. Additionally bio-scrubbers require regular attendance, generally weekly, to maintain nutrient flows. While this increases the ongoing operating cost of biological scrubbers, when considering applications of very high concentrations of H_2S gas, i.e. 200 ppm, biological scrubbers offer the least cost option for odour control.

5 APPLICATIONS, LIMITATIONS & DEVICE SELECTION

A correctly designed carbon filter can remove 99.99% of H_2S gas from foul sewer air. The carbon filter can effectively treat foul sewer air up to relatively high concentrations of H_2S gas, i.e. 100 ppm and above. However, an upper limit exists where the carbon will be expended quickly rendering the unit ineffective. Activated carbon adsorbs H_2S gas on a mass loading basis. Depending on the particular proprietary carbon used an upper limit exists, for example 287g H_2S / litre of carbon for a double impregnated Potassium Iodide & Potassium Hydroxide activated carbon. Once the carbon has adsorbed all of the H_2S gas it can, break-through of the H_2S gas occurs in the carbon filter. This means that the odour constituents of the foul air then pass through the carbon filter leading to inadequate treatment and the risk of odour complaints.

The higher the concentration of H_2S gas in the incoming air stream, the shorter time a certain amount of carbon will last, meaning that the carbon must be changed out more regularly to continue effectively treating the wastewater odour. In short, while carbon filters can effectively treat very high concentrations of H_2S gas, the operating cost climbs in a linear relationship with H_2S gas concentration. It quickly becomes very expensive or in some situations uneconomic to use carbon filters where H_2S gas concentrations are greater than 100 ppm H_2S.

It is therefore concluded that while carbon filters can effectively treat relatively high levels of H_2S gas, there are economic restrictions to the maximum H_2S concentrations that can be treated on an ongoing basis.

Biological media beds are inherently limited in their ability to treat medium to high concentrations of H_2S gas. This is for a number of reasons including:

1. Limited efficiency of removal of H_2S gas and other sewer odour constituents;
2. Adverse biological effects of high concentrations of acid gases and their by-products;
3. An inability to adapt to high short term H_2S gas loads or shock loads.

Depending on the design, type of media and residence time, a biological media bed should be able to remove 80% to 95% of the H_2S gas passing through the bed. It is generally recognised that the lower threshold for a human to detect H_2S gas is 2 ppm. The maximum safe exposure level is 20 ppm. It is noted and acknowledge that other odour compounds are likely to be in the foul air stream and may have lower minimum human detectable thresholds, however for simplicity only H_2S gas is considered.

It is therefore assumed that an odour control device must discharge less than 2 ppm of H_2S gas for it to be considered effective, i.e. for no detectable H_2S gas to be discharged. This assumption excludes air mixing, dilution and dissipation. The efficiency of removal of biological beds therefore limits the maximum concentration of H_2S gas in the incoming air stream. If an 80% removal efficiency is achieved, then a biological bed is limited to 10 ppm H_2S gas in the incoming air stream. Additionally, if a 95% removal efficiency is achieved, then a biological bed is limited to 40 ppm H_2S gas in the incoming air stream.

It is concluded that the maximum concentration of H_2S gas that can be effectively treated by a biological bed is 40 ppm.

5.1 VENTILATION – PASSIVE & ACTIVE

A primary element in the design of any odour treatment device is the question of ventilation. The two options to be considered are passive or active ventilation. Passive ventilation relies on naturally occurring air flow to force air through the odour control unit. Active ventilation requires a fan to force air through the odour control unit.

Active ventilation has obvious drawbacks with capital cost, ongoing maintenance cost and in some circumstances practicality. The primary constraint with the provision of active ventilation is the provision of a power supply. On sites with existing power supply this element is mitigated somewhat. However existing power supplies in wastewater networks are generally limited to pump stations only. A large number of locations within wastewater networks requiring odour treatment do not have power supplies present. The provision of a power supply can often be a more involved and expensive undertaking than the odour treatment device itself. Co-ordination is required with the electricity retailer, lines company and lines company contractor to establish a new supply account and new physical supply connection and supply metering. The asset owner is then liable for lines charges on the new supply which can add significant cost to the ongoing operational cost of the odour treatment device.

While active ventilation has its obvious drawbacks in the need for a fan and power supply, in many applications it is however the only effective way to address odour issues.

5.1.1 PREFERENTIAL AND FUGITIVE AIR FLOW PATHS

Wastewater systems transport two fluids – air and wastewater. This is a basic fact that is often overlooked by hydraulic designers of wastewater networks. Air flow must be accounted for in any wastewater system. Specifically a defined air flow path must be provided. This rule applies to all gravity wastewater networks, but becomes critical in gravity systems that receive pumped flow from pump stations or rising main discharges. The same rule applies to chambers or pump station wetwells that fill and empty, displacing foul sewer air.

A common cause of odour issues is transient flow events that surcharge sections of gravity pipelines, pump station inlet chambers or wetwells. The surcharged section of line blocks air flow, causing the air in the line to find another air flow path.

Air flow behaviour in wastewater networks is sensitive to very small changes in differential air pressure. Slight changes in differential air pressure, measured in milli-Pascals, can result in air flow establishing fugitive leakage paths and thus creating nuisance odours at various unintended locations.

Well-designed wastewater networks will draw air along with the wastewater flow, along the entire length of the system, delivering that air to a designed and suitably controlled location such as a pump station. Critically, a

well-designed system will maintain air flow paths throughout all flow conditions, i.e. even at maximum flow levels, an air flow path to the intended discharge point exists.

5.1.2 PASSIVELY VENTILATED ODOUR TREATMENT DEVICES

Passively ventilated odour treatment devices can work effectively where a wastewater system creates a well-defined air flow path. The air flow path must force air through the odour treatment device, but most critically the ability for fugitive leakage paths to be formed in preference to the air passing through the treatment device must not exist. For a passive ventilated system to work, air must be pressurised through the treatment device. Sufficient air pressure must be created in the wastewater pipework to overcome the airflow back pressure of the treatment device.

Given the sensitivity of air flow to follow defined flow paths, it can be difficult to create a passively ventilated odour treatment device that works effectively. Three elements must be considered to reliably achieve passive ventilation. These are:

1. Very low bed resistivity in the treatment device – i.e. low airflow back pressure;
2. Strong generation of air flow - i.e. steady fast flow of wastewater to induce reliable airflow down the line with it;
3. Lack of possible fugitive leakage paths – i.e. no concrete cracks or loose manhole lids.

In reality, it is very difficult to obtain all three conditions required for a passively ventilated treatment device to work effectively. The majority of existing wastewater networks are made from concrete manholes and with cast iron covers. The opportunity for cracks and gaps to provide fugitive leakage paths are significant. The same statement applies to pump station inlet chambers and to a degree, pump station wetwells. This can be mitigated with the use of modern construction materials such as PVC or PE pipe and PE maintenance shafts in place of concrete manholes. However the need for natural ventilation of gravity wastewater networks often precludes the effective sealing of manhole lids and access points, unless there is a specific application such as defining an air flow path to an odour treatment device.

The ability for the odour treatment device to provide sufficiently low air flow back pressure is a critical element in selecting an appropriate device for a passively ventilated odour treatment application. There are two specific design elements to consider to address this:

1) Size of the unit, and;
2) Bed air flow resistivity.

The size of the odour treatment unit is dictated by the requirement of the specific application. Primarily this is a function of air flow. The concentration of sewer gas is also a factor. The greater the air flow, the larger the unit needs to be, which in turn increases the total air flow back pressure across the unit.

The bed air flow resistivity also directly impacts the selection of suitable treatment devices. Biological based treatment devices, in particular bark beds, have an inherent disadvantage in this regard. This is as the biological process and the media substrate degrade over time, meaning that over time the bed resistivity and back pressure will increase. This process will continue until such time as the back pressure becomes excessive and air flow finds a fugitive leakage path. In effect, a bark bed will fail at some point in a passively ventilated application.

Carbon filters have an inherent advantage over bark beds in passively ventilated applications due to their significantly lower bed resistivity to air flow. It is acknowledged that carbon filters will also eventually fail in a passively ventilated application. However this is due to the carbon becoming expended, rather than changes in air flow paths. Fugitive leakage paths often only occur under certain flow conditions and can be transient in nature, making them difficult to identify and rectify in the event odour complaints are received. The prediction of failure of a carbon filter (odour breakthrough) is easier to predict than the decomposition and increase in back pressure of a biological bed. Sulphide logging into a carbon filter provides a method of recording the mass loading rate of H_2S into the bed and therefore its expected operational life, in addition to sulphide logging on the outlet of a carbon filter to verify odour breakthrough and the need to replace the activated carbon. Conversely it is difficult to quantitatively assess the condition and performance of a biological bed, instead qualitative assessment and personal opinion must be relied upon to resolve operational issues.

It is concluded that carbon filters have a number of advantages over bark beds in in a passively ventilated applications.

5.2 ACTIVE VENTILATION

In all but a very small number of applications, active ventilation is the only reliable and effective option over passive ventilation. The asset owner and designer must make an assessment of the technical effectiveness of passive ventilation, the sensitivity or criticality of a particular application or location, and the additional cost of providing active ventilation.

Certain applications are naturally well suited to passive ventilation, such as the discharge side of air valves on rising mains. This is where any air that is released, is released under pressure and can be easily piped through an odour treatment device without risk of leakage. In certain instances forced or pumped gravity mains may possess suitable hydraulics to ensure suitable air flow though a passively ventilated treatment device.

Active ventilation is well suited to a wider range of applications across the wastewater network. Pump stations, inlet chambers, gravity networks and anywhere where a negative air pressure is required to maintain preferential air flows are all applications where active ventilation is generally required.

The two primary benefits of active ventilation are that air flow back pressure of the treatment device becomes less critical, and that preferential air flow paths can be created and reliably maintained within wastewater assets and systems.

With air flow back pressure being less critical, biological beds can be used with a higher degree of reliability in actively ventilated applications. This then means that the selection of biological beds over carbon filters can be based primarily on a least whole of life cost basis, as given a suitable range of H_2S gas concentration, both options are likely to provide effective odour treatment.

5.2.1 BENEFITS OF ACTIVE VENTILATION

There are a number of benefits of active ventilation for the wastewater network and for key wastewater assets. The primary benefit with respect to odour treatment is to establish strongly defined air flow paths. This draws foul sewer air down through wastewater networks and ensures that transient flow events do not cause odour to escape the network at unintended locations, i.e. preventing nuisance odours and odour complaints from occurring at random around the network.

The primary benefit for active ventilation for wastewater assets is the prevention of asset corrosion. This is most commonly an issue with concrete assets such as wetwells, storage chambers, manholes and concrete pipework, but can also be an issue with metal such as pump station fittings, stairs, manhole and chamber lids and hinges. In extreme cases of lack of containment, H_2S gas around electrical switchboards can also rapidly degrade electrical equipment.

Active ventilation prevents corrosion by two mechanisms:

1) Dilution of H_2S gas, and;
2) Drying of surfaces.

Studies[4] have shown that active ventilation of pump station wetwells reduces the average concentration of H_2S gas. Based on a first principles assessment, it is expected that increasing air flow or air turnover in a confined space will reduce the gas concentrations, as gas production is a function of wastewater volume and dissolution from the liquid phase into the gas phase. Increasing ventilation can be expected to significantly reduce gas concentrations. This means that assets are exposed to much lower concentrations of corrosive gases, slowing or preventing H_2S corrosion of those assets. This same effect also has benefits for operator safety and the ease of wetwell maintenance, by reducing the build-up of harmful gases in confined spaces that require operator entry for maintenance purposes.

The drying of surfaces is a simple function of reducing condensation by displacing saturated air and allowing evaporation of condensation from asset surfaces. This slows or prevents growth of biological slimes on surfaces that lead to acid attack of the surface as a by-product of the slime growth.

6   APPROPRIATE SIZING OF TREATMENT DEVICES

Following the selection of an appropriate odour treatment device, the device can then be sized for the specific application at hand. The primary determining factor of treatment device size is air flow rate. Rules of thumb for sizing both carbon filters and biological beds are as follows:

- 3 seconds residence time is required for carbon filters;
- 90 seconds residence time is required for biological beds.

In both cases, the greater the residence time that can be achieved, the greater the safety factor on achieving reliable treatment.

6.1.1   CARBON FILTERS

While a residence of 3 seconds is required for effective treatment using carbon filters, a secondary consideration is the expected time to recharge, i.e. the expected time taken to exhaust the carbon. Due to carbon's low bed resistivity, there are not any adverse technical ramifications of making a carbon filter larger than it needs to be. There is however a benefit in that the larger the carbon filter, the longer the expected life before the carbon is exhausted. Given available capital budget, the operating cost of changing out carbon can be reduced by sizing the carbon filter on an H_2S gas mass loading rate, rather than on the minimum required residence time.

It is recommended that, given suitable project constraints, carbon filters be sized with respect to the mass loading rate of H_2S gas, over and above the minimum size required for residence time, so as to ensure adequate life between maintenance (carbon exchanges) and to prevent nuisance odours in the event that the carbon prematurely expires.

6.1.2   BIOLOGICAL BEDS

While it is preferable to make a biological bed as large as practical and to increase the residence time to provide a safety factor for effective odour treatment, more often than not the cost and available space restrict what is practical. Section 4 discusses practical limitations on the depth of bed and how various media options impact on this. The bed depth has a direct impact on the footprint of the bed and the achievable residence time for any given flowrate.

6.2   AIR FLOWRATE & AIR SURGES

It is common practice to size odour treatment devices on steady state air flow rates. Significant caution should be exercised to ensure that dynamic state behaviour does not dominate the wastewater system. Dynamic state behaviour leads to surging air flows and very short duration pressure spikes in systems. Surging air flows may inundate odour treatment devices causing break out of nuisance odours. Short duration pressure spikes can result in foul air being intermittently discharged from wastewater networks via fugitive leakage paths. These causes of nuisance odours are particularly hard to identify by casual observation and require dedicated methodologies as described in the technical papers "Integrated Odour Management" and "Integrated Odour Management Part 2 – Solution in Practice".

Dynamic state behaviour is generally associated with pumped systems, however the symptom of the behaviour can manifest itself a significant distance away in other parts of the network. Examples of dynamic state behaviour include:

1) Surging air flows at pump start up, where pumps start rapidly using 'direct on line' or soft starters. Downstream pipework is filled very rapidly, forcing air to surge out of the network. This can be further exacerbated where check valves do not work effectively and rising mains partially drain down, meaning that at pump start, initial pump flowrates are higher while the pump works against lower static and dynamic heads, again causing air surges further downstream.
2) Blow-back events, where flows surcharge gravity lines, generally where steep grades flatten out causing the line to surcharge. Air is dragged along with flow along the pipe soffit, but where the pipe surcharges the air flow path is blocked, causing the air flow to pressurise and 'blow back' up the line and find a fugitive leakage path out of the system.
3) Very flat gravity lines that can fill rapidly. In these situations and waves or flow surges along the line can push air out of the line at greater volumes than the rate of filling of the line.

6.2.1   VARIABLE SPEED DRIVES AND ACTIVE VENTILATION

It is good practice to install a variable speed drive (VSD) on ventilation fans. This is so that the air flowrate can be optimised post commissioning to ensure the maximum viable residence time is achieved in the odour treatment device, while also maintaining the maximum achievable ventilation or negative air pressure within the wastewater asset.

Digital manometers can be used to record air pressure and ensure negative pressures are maintained within wastewater assets during all states of network operation, i.e. pump start, line filling, line drain down, wetwell filling and wetwell emptying.

The use of VSD's on ventilation fans also allows for changes in fan air flow and increasing bed back pressure where biological beds start to degrade over time, changing the dynamics of the ventilation system.

7   CONSIDERATION OF WIDER NETWORK ISSUES – SULPHIDE GENERATION

As stated in the introduction to this paper, it is common practice for asset owners to attempt to address odour issues with the use of odour treatment devices. This practice rarely addresses the root cause of the odour issue, however with careful application, it can alleviate or adequately address nuisance odours and reduce or prevent odour related complaints.

However, the limitation of odour treatment devices to effectively deal with high H_2S gas concentrations are apparent. Biological bark beds have limited ability to deal with medium to high concentrations of H_2S gas, i.e. from 50 ppm to 100 ppm, bark beds are generally not considered effective over 40 ppm H_2S gas. While carbon filters can effectively treat high concentrations of H_2S gas (i.e. 100 ppm and above), as they adsorb H_2S gas on a mass loading rate, the cost of using carbon filters at these concentrations quickly becomes prohibitive.

While the causes of odour issues can be wide and varied, a single cause is regularly identified as the root cause for severe odour issues. This is the retention of solids within rising mains. Odour issues are primarily caused by high sulphides present in wastewater. The sulphides are released into the gas phase (H_2S gas) when the wastewater is exposed to air, and particularly around areas of turbulence and splashing. There can be a perception that septicity causes high sulphides and that septicity is caused by high residence times in wastewater, i.e. wastewater sits in wetwells too long in dry weather periods, etcetera. While this is correct, the impact of solids retention in rising mains is often overlooked.

Experience has shown that where solids are retained in rising mains, very high levels of liquid phase sulphides can be expected, and other measures of effluent strength including Bod and total suspended solids can increase by an order of magnitude above normal effluent levels. H_2S gas levels at discharge points of lines retaining solids can be expected to be very high, i.e. in the order of 80 to 100 ppm, and in extreme cases can be significantly higher again. Cases of between 500 ppm and 1,800 ppm have been recorded in downstream sections of gravity lines receive flows from rising mains that were then shown to be retaining solids.

Retained solids undergo anaerobic digestion, leading to the very high sulphides and the production of methane. The presence of methane has been recorded in examples of rising mains retaining solids. The presence of methane can pose significant complications with regards to operational health and safety in the wastewater network.

7.1   SOLIDS SELF-CLEANSING VELOCITIES

Solids accumulate in rising mains when the pumped flowrates are less than that required to achieve solids self-cleansing. There are a wide range of reasons for this to occur. Common examples are:

1) Pump impellors have worn so that flowrates have diminished over time, or;
2) That two pumps are required to achieve self-cleansing flows and that this does not occur in dry weather periods, or;
3) The rising main has been sized for either very high peak wet weather flows which cannot be achieved in dry weather, or;

4) The rising main has been sized for future growth, and these flows cannot be presently achieved.

Liquid phase sulphide levels can be reduced dramatically simply by increasing the pumped flowrate in rising mains. Four fold and more reductions in H_2S gas levels have been recorded and in certain instances where rising mains have had the solids removed. In a number of cases H_2S gas levels have been reduced to zero or near zero (i.e. 2-3 ppm) in the sewer head space, and maintained at those levels on an ongoing basis.

7.1.1   REQUIREMENTS FOR SOLIDS SELF-CLEANSING

The general rule of thumb applies that a velocity of 0.6 m/s is required to achieve solids self-cleansing. However this rule only applies for smaller pipe sizes. As the diameter of pipe increases, the minimum velocity also increases, i.e. for an 800 mm internal diameter pipe the velocity required is 0.8 m/s.

The physical mechanism required to achieve solids self-cleansing is a shear force on the pipe wall of 1.6 Pascals. The specific flowrate for any pipe size to achieve solids self-cleansing can be determined by use of the below equation:

$$Q = \frac{6.3 \times 10^{-3} \times D^{2.167} \times \tau^{0.5}}{n}$$

τ = 1.6 Pa for Self Cleansing

n = typically 0.012

Where

Q = flowrate m^3/s

D = ID m

τ = Tor = pascals shear force

n = Mannings roughness coefficient

7.2   IMPACT ON ODOUR CONTROL DEVICES

Significant benefits are available to the asset owner if rising mains can be pumped with minimum self-cleansing velocities. It is possible that the cause of the odour issue may be removed altogether, and an odour treatment device is not required at all.

With the reduction of H_2S gas concentrations biological bark beds may become a viable treatment option where they were previously excluded by excessively high H_2S gas concentrations. This gives the asset owner an increased choice and flexibility as to the selection of odour treatment devices. Further, with significant reduction in H_2S gas concentrations, the expected operational life of the carbon filter will be extended. The extension of life of the carbon filter has a direct lineal relationship with the reduction in H_2S gas concentration, i.e. if a four-fold reduction in H_2S gas concentration is achieved, i.e. from 80 ppm to 20 ppm, the carbon filter can be expected to last four times longer between recharges. This has a direct impact on reducing the operational cost of carbon filters.

The asset owner is then free to assess the relevant attributes of carbon filters and biological beds for odour treatment, rather than being constrained by the technical limitations or costs of each option.

It can be concluded that reliably achieving solids self-cleansing in rising mains has significant benefits to the wastewater asset owner.

8   CONCLUSIONS

- The ability for various carbons to absorb differing amounts of H_2S gas is of key consideration when considering the capital and whole of life costs of carbon filters;

- Multistage carbon filters with specific types of carbon to target constituent odour compounds can improve the efficiency and capacity for odour removal of carbon filters, and reduce the operating cost;
- The risk of bed fires in carbon filters used for municipal wastewater odour treatment applications is low;
- Commissioning of odour beds or renewing the bark media should be avoided during periods of hot dry weather that coincide with high sulphide loading rates and associated odour complaints;
- Carbon filters can effectively treat relatively high levels of H2S gas, however there are economic limitations to the maximum H_2S concentrations that can be treated on an ongoing basis;
- The maximum concentration of H_2S gas that can be effectively treated by a biological bed is approximately 40 ppm;
- Carbon filters have a number of advantages over bark beds in in a passively ventilated applications;
- Reliably achieving solids self-cleansing in rising mains has significant benefits to the wastewater asset owner with respect to wastewater odour issues.

REFERENCES

1 – Hydrogen Sulphide Control Manual, Monograph 8.2 Odour Adsorption, Technical Standing Committee on Hydrogen Sulphide Corrosion in Sewerage Works, Dec 1989.

2 – Technical Bulletin, Separation Technology and Materials, ABN 39 079 864 828

3 – Biology of Microorganisms, Seventh Edition, Brock, Madigan, Martinko & Parker – Prentice Hall International Editions

4 – Odour Control for Pump Stations, Holyoake, K. M. and Kotze, K.V.; Armatec Environmental Ltd, NZWWA 2010.