ODOUR AND CORROSION MANAGEMENT

A design guideline for managing H_2S and odours from sewage systems

McCormacks Bay Biofilter – PS57

4th Edition

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Contents

1 Introduction

Wastewater can generate hydrogen sulphide (H_2S) and other gases which cause odour and corrosion problems. This risk increases with increasing residence time and the use of pump stations and pressure mains, including pressure sewer systems. The release of H_2S from the dissolved aqueous phase to the gaseous phase occurs due to a number of processes but is exacerbated by turbulence.

Where the odour develops into a nuisance to nearby residents, or where H_2S causes corrosion through attack on the cement contained in pipes and manholes, removal of the odour becomes necessary.

The purpose of this document is to provide a guide to current best practice so that odour and H_2S management systems constructed are effective and efficient, and so that there is consistency throughout the design and construction process.

Municipal wastewater typically includes sulphur compounds. Under specific conditions, these sulphur compounds can be converted to H_2S, or other sulphur containing compounds (eg. mercaptans and acetates), which, in their gaseous form, are malodorous. The generation of H_2S can be due to either chemical or biochemical/microbial pathways, with low oxygen facilitating the microbial pathway.

In the gaseous form, H_2S will react with moisture on the walls of pipes or vessels. In the high humidity environment of a sewer, sulphur oxidising bacteria can convert the hydrogen sulphide to sulphuric acid. This can lead to concrete corrosion. This corrosion can be significantly worse with septic wastewater and the associated higher levels of gaseous H_2S.

This guide provides an overview of the treatment options for managing odours produced by wastewater through investigation, design, operation and maintenance, and monitoring. Checklists for design, commissioning, and operational monitoring are appended.

For guidance on protection of concrete structures against corrosion refer to Council's Design Guide "CCC DG61 - Protective Coatings for Concrete Wastewater Structures".

Version History

Version	***Title***	***Date***
0.0	Design Procedures for Biofilters	15 Jan 2010
1.0	Odour Management - A design guideline for managing odour from sewers	7 May 2010
2.2	Odour and Corrosion Management - A design guideline for sewage systems	17 Dec 2010
3.0	Odour and Corrosion Management Design Guide	21 May 2020
4.0	Odour and Corrosion Management – A design guideline for managing H2S and odours from sewage systems	27 Sep 2022

2 Background

2.1 Wastewater Odour Origins and Composition

Odour generated from wastewater is composed principally of H_2S but incorporates other volatile organic compounds such as mercaptans, acetates and amines (Harsham, 2008).

H_2S inhalation can be fatal and great care should be taken around any potential sources. At just 0.00047 ppm (0.47 ppb), half of all people can detect the characteristic “rotten egg” odour of hydrogen sulphide.

H_2S concentrations can be estimated from Figure 1 below (Data ex Wiki, 2021) and confined space limits for human H_2S exposure are listed in Table 1.

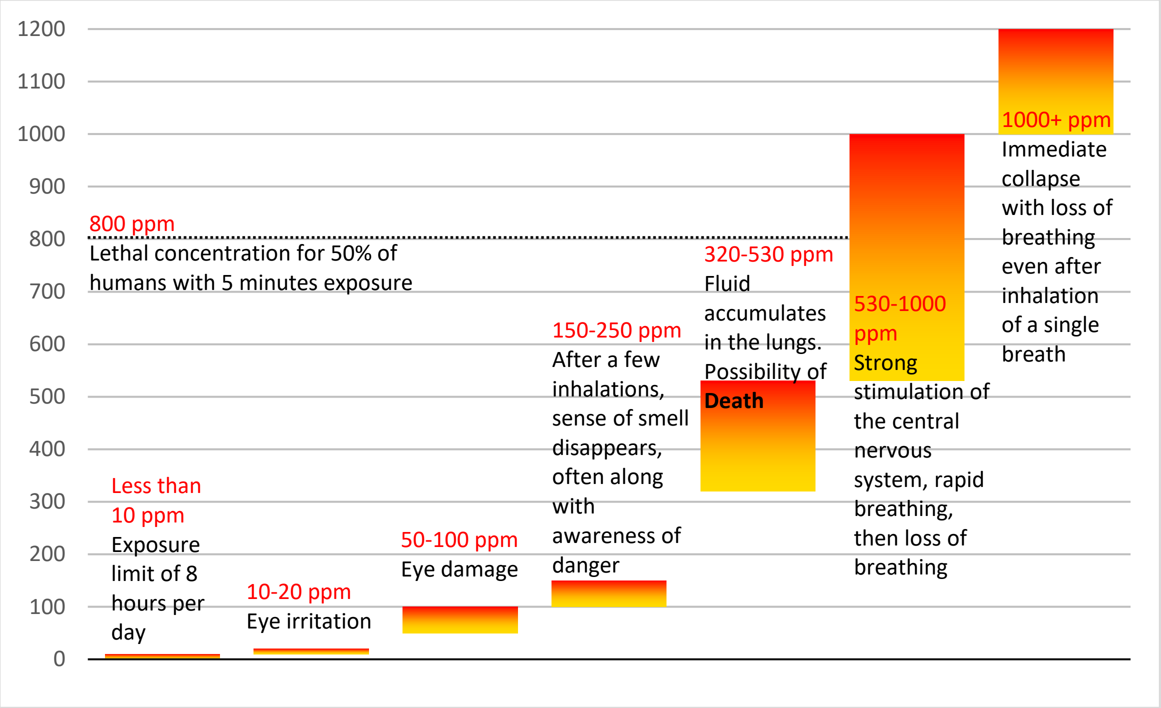


Figure 1: H2S concentration and the effect on humans

Table 1: Confined space limits for human H_2S exposure

Parameter	ppm	Comment
Ceiling	35 ppm	May not be exceeded for any time
STEL	15 ppm	Short term exposure limit
TWA	10 ppm	Total weight average (8 hours)
IDLH	100 ppm	Immediately dangerous to life or health
Vapour density	1.2	Relative to air density (ie. H_2S is heavier than air)

To mitigate against these dangers, the Council requires all persons entering manholes or other confined spaces related to the wastewater system to hold a current "Confined Spaces Entry Permit" and comply with applicable legislation requirements.

The odorous gases typical of wastewater are summarised in Table 2. Typical Christchurch wastewater composition and the potential ultimate gas emissions are shown in Table 3.

Table 2: Typical wastewater gases

Group	Source	Chemical Code	Human detectable odour threshold	Note
Fatty Acids (Butyric Acids)	as acetate *(acetic acid)*	CH_3COOH	1.0 ppb	
Hydrogen Sulphide	ex salts/inorganic sulphur	H_2S	0.47 ppb	lethal at 300 ppm
Methyl Mercaptan	ex protein/organic sulphur	CH_3SH	2.0 ppb	

Table 3: Typical Christchurch wastewater composition and the potential ultimate gas emissions were determined in a study for the Christchurch Wastewater Plant as below.
(ex Brown and Caldwell, 1973)

Group	Typical Chch concentration	Vapour Pressure	Gas release at 100% conversion	Volume Conc. in 1 Litre of Air	Reqd Dilution to detectable limit
Acetate (Fatty Acid)	28 g/L	3.3 kPa	1.1 cc/L	1000 ppm	1x10^6
Hydrogen Sulphide	2 mg/L	1860 kPa	1.3 cc/L	1300 ppm	3x10^6
Methyl Mercaptan	0.32 mg/L	101 kPa	0.15 cc/L	150 ppm	7.5x10^4

The above numbers are based on "typical" source concentrations for Christchurch sewage and include a number of approximation assumptions in deriving the potential gas concentration yields.

Volume concentrations in 1 litre of air (as tabulated) would occur if 100% conversion of the source matter to gas occurs for each source type, that there is sufficient time and turbulence to allow the gas to release, and the air extraction rate (L/s) matches the sewer flow rate (L/s). Of note is that H_2S requires the highest dilution to bring the gas levels down below detectable limits.

If an odour filter intercepts 99% of odorous gas and the air extraction rate is say 5x the sewage flow rate then the residual gas emission will be 1300/5 * 1% = 2.6 ppm which will still require a further 5000x dilution to drop the H_2S levels below detectable levels.

Fresh sewage typically has a high biochemical oxygen demand (BOD) that is met by oxygen uptake where an air supply is available. In the absence of oxygen then sulphur, with very similar oxidising ability to oxygen, acts as the electron receiver. Hence the production of odoriferous gas molecules in anaerobic conditions and the need to maintain ventilation to the atmosphere wherever possible to limit the sulphur reactions.

2.2 The Primary Methods for Treating the Airflow

There are a number of accepted methods for treating the airflow to remove odour including hydrogen sulphide that are in use in New Zealand and elsewhere.

Biofilter – Generally comprised or bark nuggets, a mixture of bark nuggets and mussel shells or other organic products such as coconut husks; sometimes compost is mixed in the media - this functions by passing the gas from the wastewater system through a media bed, to allow the adsorption of the gases onto the media surfaces, where they are degraded by bacteria. Biofilter typically have no moving parts other than a fan. Over time, the media bed degrades into a fine organic material which impedes air flow and will require replacement.

Bio-scrubber – this functions by passing the gas from the wastewater system through an inert media bed. Moisture and nutrient supply are required to sustain a microbial population. The microbial population forms a slime (or biofilm) on the media as organic compounds are absorbed or adsorbed and the population grows. The slime will eventually slough as it thickens with time. Sloughed biofilm solids require periodic removal.

Activated carbon – this functions by passing the gas from the wastewater system through an activated carbon media bed. The H_2S is adsorbed onto the media. Over time, the media's capacity to adsorb H_2S is reduced and the media will require replacement.

Wet air or chemical scrubber – these function by passing the gas from the wastewater system through a chemical solution, allowing the odour causing compounds in the gas to either react with or dissolve into the liquid. These scrubbers can be installed in series using different chemicals e.g. carbon dioxide, in each scrubber to remove different compounds.

3 Objectives

The initial step in the design process for an odour treatment or corrosion management system is the setting out of the issues and defining the solution objectives. These might include:

- Prevent odour nuisance to adjacent residents.
- Achieving the specified infrastructure design life by preventing future deterioration of current or future assets by not exceeding a specified H_2S concentration or by the addition of appropriate protective coating.
- Reducing or eliminating odour complaints at a specific point.
- Providing treatment to mitigate against the expected odour or H_2S created by the upgraded existing or new infrastructure, through preventing the H_2S concentration exceeding a specified value.

The objectives are typically project specific and are intended to ensure the efficient use of funds and the construction of robust sustainable solutions.

Site measurements and observations will generally be required.

4 Investigation

The investigation stage of the project includes gathering background information and data. This information may disclose conditions and constraints that will impact directly on treatment system selection, design and operations. Data can include odour complaint records and historical H_2S measurements generally within nearby manholes. An on-site reconnaissance and / or more thorough and targeted data collection program and analysis may be required.

4.1 Historical Data

Council has an historic record of odour complaints received and their locations. This may also provide information on seasonal variations at a site.

Council holds asset data including pipe material and often closed circuit television (CCTV) condition assessment records. If the pipe material is cement based (concrete or asbestos cement (AC)) and H_2S is present, examine the CCTV record of the sewer to determine if corrosion is an issue. If this is not already available for these pipe materials at this location, arrange for a CCTV inspection to be undertaken. This is especially relevant for pipes immediately downstream from pressure and local pressure sewer system (LPSS) discharges, trade waste discharges and gravity pipelines containing aged sewerage as is typically the case with large diameter trunk mains, reliefs and interceptors.

4.2 Site Information

The initial site assessment should investigate:

- On-site odour problems.
- Pipe and manhole corrosion.
- Network configuration.
- Location of vented manholes.
- Wastewater age.
- Presence of turbulent flow conditions.
- Future flow and likely future H_2S loading.

Environmental factors to be evaluated include:

- Groundwater levels.
- Whether the site or any below-ground structures will be susceptible to surface flooding or flooding due to changes in the groundwater level.
- The possible effects of downstream sewer main blockages.
- The site’s proximity to housing, with relation to noise and odour impacts.
- The ambient noise environment.
- the upstream pipework including possible sources of odour and humidity
- Local weather conditions e.g. the prevailing wind direction, rainfall including duration and intensity.
- Physical constraints e.g. shade, fencing requirements, public access over the site, maintenance access, the shape of the site.
- Possible leachate drains discharge points.
- Utility connection points.

4.3 Wastewater Composition

Wastewater composition data can be used to assess wastewater quality and the risk of septicity. Quality instruments are available that are capable of producing immediate water composition results such as:

- pH
- Oxidation-Reduction Potential (ORP)
- Dissolved Organic Carbon (DOC)
- Temperature
- Conductivity
- Turbidity

For ORP in particular the reaction state correlates with the values shown in Table 4. When ORP (mV) is in the range -50 to -250 mV sulphide production is likely to be a downstream network issue.

Table 4: Biochemical Reactions and Corresponding ORP Values

Biochemical Reaction	*ORP, mV*
Nitrification	+100 to +350
cBOD degradation with free molecular oxygen	+50 to +250
Biological phosphorous removal	+25 to +250
Denitrification	+50 to -50
Sulphide (H_2S) formation	**-50 to -250**
Biological phosphorous release	-100 to -250
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400

The saturation of H_2S and sulphur ions in the wastewater stream correlates with pH as shown in Figure 2 below. As can be seen an alkaline state beyond a pH of 9 will eliminate the presence of H_2S.

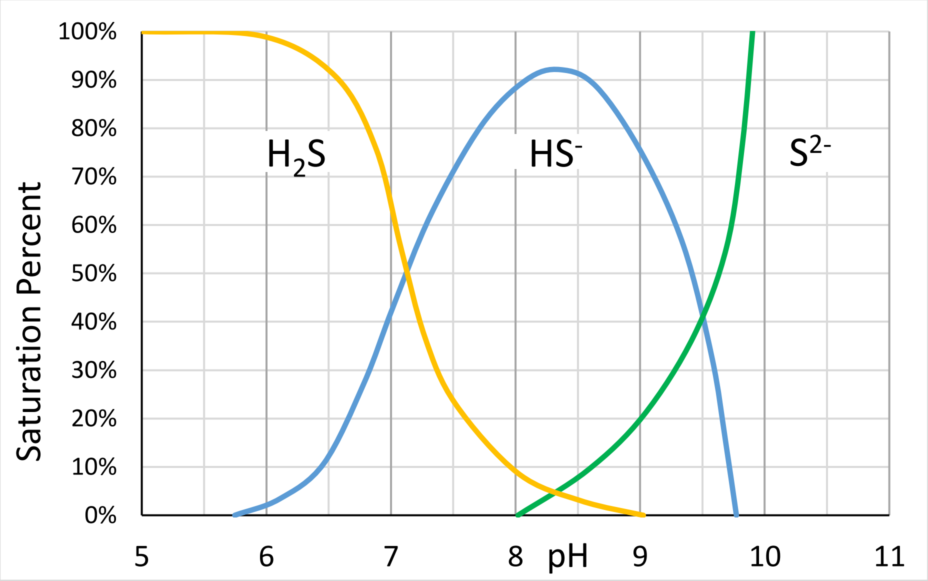


Figure 2: Wastewater pH versus H_2S, HS^- and S^{2-} Saturation Percent Graph

4.4 On-site Measurement of Compounds within the Airflow

Odour is generally mostly composed of H_2S but does include other strongly odoriferous organic components that give sewage its characteristic odour. An important component of the on-site measurement is measuring H_2S and these other components within the airflow, to provide background data including:

- Upstream and downstream pipeline H_2S concentrations. This will provide a longitudinal view of the concentrations.
- Other compounds present in the air stream especially mercaptans.
- Results at a range of air extraction rates.
- Concentration variations throughout the year.

Concentration measurements are made in conjunction with airflow rate measurements to allow the determination of the H_2S mass flow rate.

Odour may be very noticeable to the wider community during the airflow test. Passing effluent air through a temporary mobile activated carbon treatment unit and notifying those likely to be affected beforehand and explaining the temporary nature of the odour should allay any complaints.

Test wastewater samples to determine the dissolved and total sulphide content. If an air scrubber or a carbon filter may be an option, include the VOCs (Volatile Organic Compounds) concentration and the ratio with H_2S.

Where corrosion is an issue, use a portable extraction fan to draw measured rates of air out of the selected manhole and record the H_2S concentrations and airflow rates. Test at several locations on the system, including the complaint location and the upper and lower end of the affected sewer.

The tested rates of air extraction should cover a range of possible airflows through the treatment device, to mimic the design situation as closely as possible and to determine the variation of the H_2S concentration over time. In this way, the optimum air-extraction location and the possible effect of various airflow extraction rates on H_2S concentrations may be determined.

When gathering base data, it is desirable that measurements include at least part of the mid-summer period, as H_2S concentration are highest in warm temperatures. Be aware that during and immediately after severe wet weather, the level of H_2S will drop, particularly in the outfall sewers of large older catchments with groundwater inflow. This is due to reduced dissolved sulphide concentrations in the diluted wastewater stream leading to reduced concentrations in the airflow.

Where possible, assess the sewer over the full year to estimate the annual average and peak load times.

4.5 Equipment and Software

Council monitors H_2S using several Odaloggers and software supplied by Associated Process Controls Ltd, Auckland (www.apc.co.nz). These instruments are held by Citycare with requests for monitoring managed by the Wastewater Operations Team. Instruments currently in use are capable of reading up to 1000 ppm with a 1 ppm resolution but other instruments include sensors that record up to 2 ppm, 50 ppm, and 200 ppm with higher resolution.

4.6 Initialising and Downloading the Data

An infrared serial interface is required.

Before recording the data, programme the computer with the job name and logging interval through the infrared link. The normal recording interval is 60 seconds, giving about one week of readings but it can be any integer from five seconds to hours.

Downloading the data to the computer is done through the infrared link and the software allows graphing or spreadsheet (.csv) reporting of the data. It is important to save to a new file name that describes the project, including at least the asset ID, location and date, as the default filename is a combination of the instrument serial number and the date and this becomes meaningless in a very short time.

4.7 Installing the Odalogger

Select an Odalogger with a data range appropriate to the expected H_2S concentration:

- In gravity sewers other than those close to rising main or LPSS discharge locations, a 0-200 ppm range will generally be adequate.
- If testing near a rising main discharge or LPSS with possible high intensity H_2S, start with a 1000 ppm maximum reading Odalogger.

Set the Odalogger as low in the manhole as practical but above the highest sewage levels, to prevent the possibility of the Odalogger being swamped. Frequent high operational levels will show on the manhole walls. If the sewer is known to gorge in wet weather, retrieve the Odalogger from the manhole on receipt of a wet weather forecast and prior to gorging.

Odaloggers are water-resistant when hung vertically. Beware of splashes that could wet the H_2S sensor in the bottom of the unit.

Hang the Odalogger in the manhole by:

- Using a plastic manhole dust tray. Drill a hole in the tray and pass a polypropylene rope through and into the manhole. Tie the rope to the tray's lifting handle and suspend the logger below. Note that there are two dust tray sizes in Christchurch and if the smaller one is used in the larger opening size it may fall in.
- Fixing a stainless steel bracket with a rawl plug bolt in the manhole neck. Tie the rope to this and suspend the logger below.

Note that sensor replacement is expensive!

4.8 H_2S Mass Calculation

Measurements to allow H_2S mass calculations are carried out at manholes. The H_2S mass calculation should be from data measured within the pipe but airflow velocities in gravity sewers are not convenient to measure as they are generally less than 0.2m/s. The airflow, in a minimum grade sewer flowing at less than 0.25m depth, is likely to be very slow and it is highly influenced by wind shear from air coming in road or property vents.

Drawing air out of a manhole at a known airflow rate and recording the H_2S concentration will give an accurate estimate of H_2S mass flow rate. This is determined through multiplying the H_2S concentration by the airflow rate.

4.9 On-site Measurement of Humidity

Relative airflow humidity is measured using a hydrometer. Measurements of the moisture content and temperature are taken over a 24 hour period, to return a plot of the relative moisture content.

Humidity of the airflow impacts on the effectiveness of some treatment systems, particularly for options other than biofilters. eg. activated carbon filters. Measurements by Christchurch City Council have found that sewage airflows have moisture contents over 95% and the relative humidity increases over winter.

4.10 Vacuum Pressure Measurement

In order to prevent the escape odours from an otherwise odorous source that source should always be at a negative pressure relative to atmospheric pressure. This is especially an issue with pump station wet wells where the various changes in flow state and wet well levels have the potential to displace air at a rate that overwhelms the air extraction system – especially when that system is in a deteriorated state. These excess pressures can be very low (< 5 mm H20 equivalent) and be transient in nature. In order to detect such transients the installation of a precision micro-manometer plus data logger can be very informative. Council has such a device but they can also be hired from some technical equipment agencies.

5 Design Parameters

Design parameters provide a framework against which to assess the effectiveness of differing methods of treatment. They can also provide a degree of consistency when determining the treatment options.

Parameters may be specified in the project brief, defined by the objectives or they may be determined indirectly from other requirements. It is important to define the parameters as accurately as possible, to assist in selecting the best design solution.

- Revisit the parameters at regular intervals during the design process to ensure that the proposed solution and the parameters are still compatible.
- When laying out the parameters, ensure that constraints in their applicability to a particular solution are stated i.e. include the assumptions upon which the parameters are based.
- Parameters may derive from environmental constraints which can restrict the available treatment options and therefore the achievable concentrations.

Examples of parameters include:

- Site space or height constraints, including space for an electrical cabinet and reduced pressure zone (RPZ) as required.
- Design solution aesthetics appropriate to the site.
- Not exceeding the maximum H_2S values at a specified point in the network.

  eg. 1 ppm peak; 0.3 ppm average over a 24hr period
- Treating a required airflow rate.
- Treating a required H_2S mass flow rate.
- Reducing the dissolved sulphide concentration within the wastewater flow.
- Reducing or eliminating the complaint frequency.
- The target odour levels at the boundary (might be zero if adjacent to a residential site).

There will also be limitations with each treatment option and the parameters it can achieve. The selection of a treatment system can be influenced by the following factors:

- The airflow rate required to adequately ventilate the sewer or pumping station.
- The peak and average H_2S, the degree of variation and the H_2S concentration (measured at the proposed airflow rate).
- The presence of other volatile organic compounds (VOCs). VOCs are usually more odoriferous than H_2S and their efficient removal requires a higher pH than is needed for the removal of H_2S.
- Post pipe renewal increase in H_2S: If pipe corrosion is serious enough to trigger renewal of the concrete or asbestos cement sewer or manhole, assess the increase in H_2S that will occur after pipe renewal. This post-renewal increase in H_2S concentration is due to the reduction in thiobacillus bacteria on the pipe wall after renewal and alkalinity released from the dissolution of the concrete or asbestos cement asset. The bacteria act in a similar way to a biofilter through using up the H_2S and converting it to sulphuric acid. The prevention of corrosion through the change in material therefore comes at the cost of an increased concentration of H_2S. Increases in H_2S of the order of 400% have been observed after

changing from corroded asbestos cement to polyvinyl chloride (PVC). Odour complaints have also started after the renewal when none were previously recorded.

5.1 Extent of Reticulation Ventilation

The airflow rate must be adequate to reduce the residual H_2S down to a low value (<1 ppm average) along the whole length of sewer to mitigate both odour nuisance and H_2S induced corrosion further downstream. Sewage which is causing corrosion will contain dissolved sulphide that comes out of solution, supplying H_2S continuously down the sewer with a higher concentration at locations of turbulence. The gas may need to be extracted at additional locations downstream to maintain low levels.

Whenever possible, locate an odour treatment system at the downstream end of a length of pipeline to utilise the advantage of the induced airflow caused by the shear effect of moving sewage in a pipe.

Gravity Reticulation Odour Issue - with No Major Odour Source within 500m.

Vent the reticulation at least 500 x Pipe ID upstream and downstream of the air extraction point and 100m minimum.

Ensure the far end manholes and connected building vents provide a vent inlet area in both directions greater than Half Pipe Area.

Gravity Reticulation Odour Issue - with Major Odour Source(s) within 500m

The air extraction rate to be sufficient to ventilate the reticulation back to the primary odour source point and any down gradient locations within 500 x Pipe ID downstream where turbulence occurs such as manholes where multiple inflows intersect.

Pressure Main Discharge

The air extraction rate to be sufficient to ventilate the discharge manhole and the downstream gravity reticulation for a distance of 1000 x Pipe ID and must also exceed the pressure main peak sewage discharge rate by 10%.

In general the odoriferous air should be extracted at the downstream end of the required ventilation length but the extraction point can be at some mid-point if this can be demonstrated to be capable of ventilating the entire required pipeline ventilation length.

Provide an air inlet at the pressure main discharge manhole and seal all intermediate air inlets.

In some cases the discharge gravity pipe diameter should be increased in size for at least the first manhole length to provide a guaranteed vent space during peak pressure main discharge.

Where there are a significant number of vented laterals connected to the target ventilation length then there will be an exponential drop off of vacuum pressure and air flow rate due to air inflow from the lateral building vents, especially with smallish diameter main line pipes. Where this is an issue then a new gravity pipe length with no laterals should be provided and this pipe should be sized so that it never flows more than half full.

All pipes and manholes over the ventilation length are also to be made corrosion resistant. (See CCC, 2022: IDS Part 6 Cl.6.13.6 and CCC, 2022: DG61)

Pump Station Wetwells

All pump station wetwells are to be provided with venting. Ensure that air admission to the wetwell is unimpeded and cannot flow in the reverse direction. An air inlet vent stack may be required. Consider air-flow dynamics and avoid short-circuiting and the creation of stagnant zones. Pump station wetwells also require an anti-corrosion coating. (See CCC, 2022. DG61)

Air Valves

For air valves creating an odour nuisance a passive odour treatment device may be required. This topic is covered further below in Cl.5.2 Airflow Rate and Cl.8.10 Air Valve Odour Treatment.

5.2 Airflow Rate

For Gravity Pipes an airflow of 1 m/s velocity, with fan assistance, in the half pipe airspace is a reasonable target. Then determine the required extraction system suction head by undertaking a headloss/airflow calculation for the local pipe network, based on a half full pipe, through to the various air inlets including road vents (which can be sealed if necessary) and laterals to building roof vents. In some cases the addition of special air inlet vents will be required.

The actual air inlets must be identified and documented in the design report.

For **Pump Stations** the wet well air extraction rate must also exceed the peak volume rate of rise of the wetwell level. Assume the station's peak pumping flow rate or demonstrate that it is some other value. Also ensure there are at least 12 wet well air changes per hour (12 ACH).

For **Air Valves** the odour treatment system should be sized to handle the typical air emission rates with an over pressure bypass included as required to handle transient induced emissions. The typical air emission rates are likely to require field measurement prior to sizing the treatment device.

Reduce the H_2S concentration at the treatment system inlet by dilution and increasing the air flow as required to achieve concentrations no more than the average and maximum values in the table below.

Table 5: Treatment type average and maximum H_2S levels

Treatment Type	*Average*	*Maximum*
Carbon Filter	2.5 ppm	30 ppm
Biofilter	40 ppm	200 ppm
Bio-scrubber	50 ppm	500 ppm

5.3 H_2S Mass Flow Rate

The H_2S mass flow rate is an important parameter for determining the activated carbon media life as all filters have a finite H_2S mass adsorption capacity. Mass flow rate measurements can therefore be used to determine a filter media's time to replacement.

H_2S mass rate affects the life of the bark media in biofilters because a high mass rate produces more acid and therefore increases the degradation rate of the media.

6 Concept Design

The concept design stage is the evaluation of a range of differing methods for achieving the same goal. Whilst there are various treatment methods for removing H_2S listed below, there may also be alternatives to direct treatment that could reduce H_2S production. Assess the conveyance system in a holistic way when considering concept design options. Consider nearby receptors as part of the process for selecting the odour treatment design solution.

When comparing the options, ensure that life cycle costs are included, as items like media replacement and installation can be significant.

Indicate any impacts on the existing network including risk of H_2S degradation of concrete assets. Also consider air inlet location(s) for ventilation. Existing vented manholes may need to be sealed or a new vented manhole may need to be installed to optimise H_2S removal. Consider if there is an existing odour treatment system nearby that can be retrofitted to remove multiple odour sources.

6.1 Options

The treatment options currently available in Christchurch include:

- Biofilters
- Bio-Scrubbers (Bio-Trickling filters)
- Activated Carbon
- Wet air or chemical scrubbers (mostly used for industrial odours)

Other options may include methods to mitigate against or control the creation of H2S within the system. These can include:

- Splash structures - these create high turbulence and can be used to encourage dissolved hydrogen sulphide to come out of solution at a pre-determined location, then treating the corresponding increased H_2S above the wastewater level at the site.
- Lowering the humidity, which can inhibit the growth of bacteria and thus reducing the production of acid on the pipe walls. The bacteria require a moist environment to thrive.
- Applying a non-cementitious coating to pipes and manholes in areas with H_2S to extend asset life.
- Periodic surcharging of corrosion prone sections of the sewer pipe, which could scour biofilms, stunting bacterial growth and reducing the production of sulphuric acid.
- Chemical dosing to lower dissolved sulphide concentrations within the wastewater flow. (Generally expensive, financially unviable and incurs a high carbon footprint).
- Aeration through the pumping of air into the wastewater wet well to displace dissolved H_2S gasses out of solution with dissolved oxygen alleviating anaerobic conditions and transport of sulphate-reducing bacteria. Odour treatment is required to remove H_2S from the wetwell. Air inlet design and location in the wet well requires design consideration. Telemetry is required to optimise operation of the air pump(s) including isolating the air pump(s) before activating the wastewater pumps as the presence of air bubbles can result in cavitation of wastewater pump components.
- Adding oxygen to the wastewater flow using a form of air entrainment, to alleviate anaerobic conditions and so reduce H_2S production. (Generally quite expensive and only effective over short pipe lengths).

- Ozonation of wastewater within a wet well to oxidise H_2S and other odourous compounds. Rather than displacing dissolved H_2S gasses, the high oxidation / reduction potential and solubility of ozone efficiently converts reduced compounds into oxidized products including ammonia into N_2 gas and H_2S into sulphate (SO_4^{2-}). Ozone also destroys the cell walls of sulphate reducing, thiobacillus and other bacteria. Similar odour treatment considerations are required as with wet well aeration.

The diagrammatic charts below provide a comparison between the various options, to aid in the selection of concepts for further consideration.

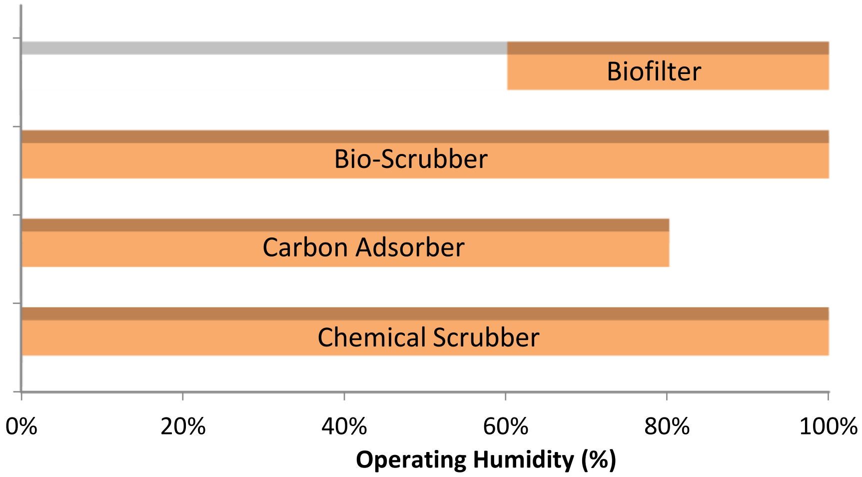


Figure 3: Chart showing effective operating humidity ranges of the various treatment systems with no pre-treatment of the airflow. Activated carbon is affected by higher airflow humidity so the unit must be fan-driven and include a heating unit to keep the media dry.

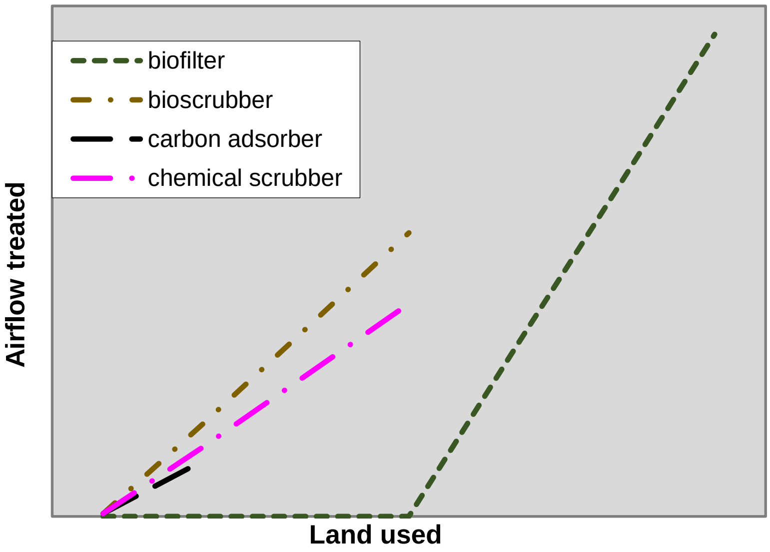


Figure 4: Chart illustrating required land area versus airflow rate. Note: Large airflows in a bio-scrubber/trickling filter can lead to treatment system heights greater than 5m.

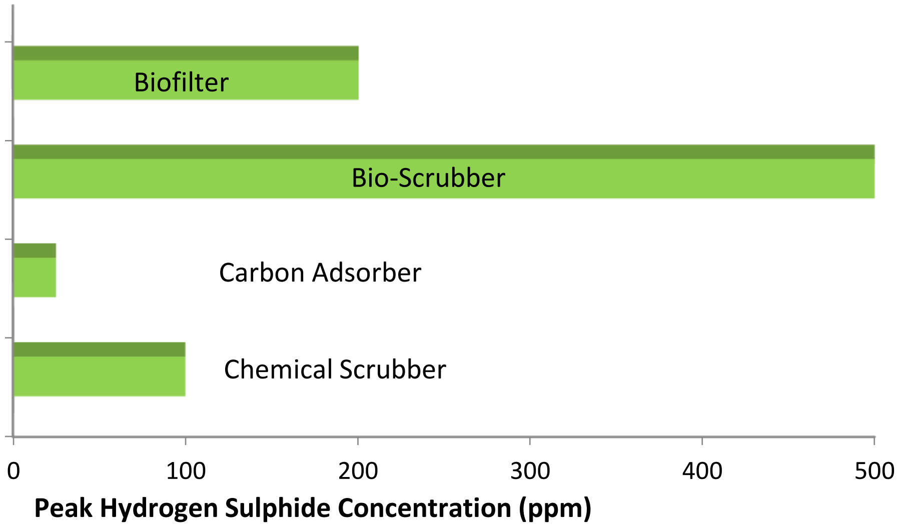


Figure 5: Chart showing the effectiveness of the treatment types in dealing with various levels of hydrogen sulphide. A form of air polisher (e.g. a biofilter or carbon adsorber) will be required to remove the last 5% of the H2S concentration in the airflow discharging from a bio-scrubber/trickling filter. Where the airflow in a carbon adsorber is low, a higher peak concentration can be treated.

The four technologies have similar life cycle costs at medium H_2S concentrations. At this concentration, factors other than the life cycle cost can influence the technology choice.

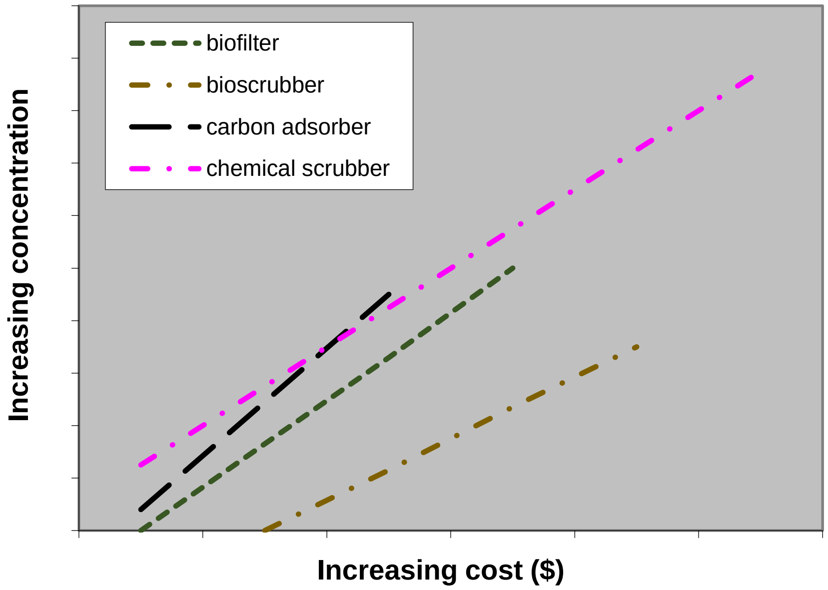


Figure 6: Chart comparing the treatment costs versus H2S concentration for the various treatment types.

6.2 Biofilters

Biofilters can be designed to treat all concentrations of H_2S and can readily handle H_2S concentrations over 30 ppm. Biofilters require regular servicing and a larger land area than other treatment options. A biofilter shall be installed no closer than 25 m to a residential property.

Photo: Ferrymead Biofilter for the PM57 discharge odours. Media almost entirely above ground level with a surrounding timber containment wall. Station ID OC0454.

A biofilter's efficiency is very dependent on treatment being carried out under the optimum conditions. A robust process for determining and maintaining these parameters will ensure a biofilter performs as designed.

- Backpressure - Biofilters should be designed to operate at a maximum differential pressure of 700Pa. This reduces fan running costs and high pressures can cause short circuiting of airflow resulting in odour emissions. See further notes on air flow headloss calculations in Section 7.6 and on air fans in Section 7.7.
- pH - The optimum pH of the media bed should be in the range of pH5.0 to pH8.0, to foster good bacteria populations, diversity and health.
- Empty Bed Residence Time (EBRT) defined as Volume of the bed (m^3) divided by the airflow rate (m^3/s). Maximise the Empty Bed Residence Time in the design, to increase the H_2S removal and odour release factor of safety. Recommended Empty Bed Residence Times to achieve 99% H_2S removal are shown in Table 6 below.
- H2S Loading - A biofilter's maximum H2S loading should not exceed 6 g/m^3 of media per day.

Photo: Pumping Station 11 Biofilter Randolph St - Station ID OC0477. Timber edging with media mostly below ground level.

Table 6: Recommended Empty Bed Residence Times to achieve 99% H_2S removal are:

Location	***H_2S level at inlet***	***EBRT***
Close residential: > 25m and < 200m separation on wind line	low peak H_2S (<5 ppm)	300 seconds
Close residential: > 25m and < 200m separation on wind line	high peak H_2S (>200 ppm)	500 seconds
Distant residential: > 200m separation on wind line	low peak H_2S	150 seconds
Distant residential: > 200m separation on wind line	high peak H_2S	300 seconds

Note: the H_2S concentrations above are for the airflow rate being fed to the biofilter.

An example of biofilter sizing based on all the parameters above is included in Section 7.5

6.3 Activated Carbon Filters

Activated carbon filters require a low relative humidity in the incoming airflow to operate efficiently. At sites of high relative humidity this will rule out this form of treatment. It is a Council requirement that ALL activated carbon filters are fan-driven with a heater installed. The only exception is where odour mitigation is required from air valves due to intermittent nuisance odour releases.

The activated carbon filter has the lowest life cycle cost when the inlet H_2S concentration is low, eg. an average of 2.4 ppm. This is because the frequency of carbon changing is reduced and its simple design minimises power consumption. An average H_2S concentration of 2.4 ppm is typical for vented pump stations where the inflow is entirely from a vented gravity network.

Photo: Settlers Crescent Carbon Filter for PM47 Discharge Odour Control – Station ID OC0501. Includes a 250mm wide concrete ring base pad to give an exposed concrete width of 150 mm.

The activated carbon filter has the highest life cycle cost when H_2S mass flow rate is high or the inlet H_2S concentration is high. eg. 20-30 ppm. In high sulphide mass flow situations or high concentrations, the media is used up more rapidly, shortening its life span.

Carbon filters can be useful for polishing of the exhaust airflow from other treatment options such as bio-scrubbers but are more often standalone units for low intensity intermittent H_2S.

Advantages and dis-advantages of Activated Carbon filters are summarised in the table below.

Table 7: Key advantages and disadvantages – Activated Carbon

Advantages	*Disadvantages*
■ Able to treat variable flows ■ Ease of installation ■ No water or chemicals required ■ Good as polishing step (post bio-scrubber)	■ High loads lead to high media replacement costs ■ Media efficiency monitoring required for media replacement

Activated Carbon filters are generally proprietary devices and the design is therefore specific to the installation. See Section 8 for Activated Carbon Design Guidelines.

6.4 Bio-Scrubbers

Bio-scrubbers can handle higher H_2S and odour concentrations but must include an activated carbon polishing system to achieve acceptable discharge odour levels in residential areas. They are also able to adapt to variable H_2S concentrations in the airflow but deleterious effects from shock loading must be considered. The polishing system will be of the same order of size as the bio-scrubber filter housing.

Christchurch City has limited experience with bio-scrubbers but two have been installed in locations of high H_2S but very limited space. A photo of a bio-scrubber installed at Clifton is shown in the photo in Section 9.

This bio-scrubber treats an average H_2S concentration of 30ppm, a maximum concentration of 130ppm and an airflow of 150m3/hr (42L/s). The required scrubber unit, including the carbon polisher, fits within a cabinet 1.3m x 1.3m x 2.4m length.

Large airflows requiring treatment can result in large diameter and/or tall scrubbers and this may be an issue visually.

Advantages and dis-advantages of Bio-scrubbers are summarised in the table below.

Table 8: Key advantages and disadvantages – Bio-Scrubber Odour Filter

Advantages	*Disadvantages*
▪ Filter media is inert (e.g. plastic or zeolite) and does not degrade over time ▪ Ability to control the environment within the unit increases removal efficiency ▪ Different operational zones can operate, optimising the removal of odorous compounds ▪ Small footprint required ▪ Capable of treating acid degradation products of VOC	▪ Additional instrumentation ▪ On-going chemical costs ▪ Large peaks in concentration can upset the microbial process and may cause odour breakthrough events ▪ Can take time for microorganisms to establish ▪ Undesirable visual profile with a large vertical tower ▪ Complexity in construction and operation ▪ Secondary waste streams

Bio-scrubbers are generally proprietary devices and the design is therefore specific to the installation. See Section 9 for Design Guidelines.

6.5 Wet Air or Chemical Scrubbers

Wet air or chemical scrubbers are a specialist treatment type used primarily for industrial odours and rarely used for wastewater reticulation odours. Christchurch City has no experience with these and does not anticipate their use. As such their design guidelines are not included in this manual.

6.6 Splash Structures

Splash structures can be used to generate turbulence and facilitate the transfer of H_2S into the airflow, where dissolved sulphide concentrations exceed 6ppm in the wastewater flow. These structures can achieve up to a 50% reduction in the wastewater flow's dissolved H_2S concentration at that point.

Splash structures should 'drop' the wastewater flow the greatest distance available**, ideally not exceeding 900 mm,** to maximise the turbulence and opportunity for H_2S to come out of solution. Outfall structures can be constructed above ground where there is insufficient depth available below ground.

7 Biofilter Detailed Design

The detailed design of a biofilter includes:

- the constructed items,
- commissioning,
- irrigation,
- monitoring requirements including frequency and monitoring points, and
- maintenance and its interaction with the monitoring results.

Include the expected performance criteria in the design report and also the O&M manual.

The biofilter design should ensure that there is an even distribution of flow through the bed and should prevent short-circuiting of gas, which can cause odours or prevent the achievement of adequate residence times.

7.1 Biofilter Media Bed

Factors to be determined are the bed:

- shape
- cross-section
- depth

The plan shape is not critical and the available location often dictates the plan layout. Generally, it is best to avoid long narrow rectangles unless air inlets are provided at the third or quarter points to reduce the pressure drop in the header pipes. The bed width is generally restricted to a maximum width of 6m as excavators cannot bridge greater widths to excavate spent media. Long narrow beds may therefore be unavoidable in some instances.

Sloping sides of around 45 to 60 degrees are preferred to prevent the media shrinking and separating away from the vertical sides, causing gas leakage. Where vertical sides are unavoidable, horizontal air leakage barriers placed around the periphery of the bed can be used to help prevent short circuiting e.g. polythene skirts fixed to the timber surround that extend a short distance into the bed. Figures 10 and 11 in Section 7.10 show typical layouts. Where battered earth slopes are used it has been found useful to provide low timber edging to give clear definition to the boundary of the filter and to provide a mount for the required irrigation sprinklers.

The media depth must be adequate to prevent short-circuiting. The minimum depth for new biofilters is **1.0** m and the maximum depth shall not exceed **1.2** m.

Operational experience has shown that substrates of this depth range reduces the likelihood of bed short-circuiting and reduces the site footprint. Depths any greater increase the likelihood of airflow restriction and early compaction blockage.

Ensure the adjacent land surface falls away from the biofilter bed for good drainage.

Refer to the example biofilter cross section drawings shown in Figures 10 and 11 appended at the end of this section.

7.2 Biofilter Media Specification

Factors to be determined are the media's:

- type
- surface area
- composition
- air voids and airflow porosity
- pH

The WEF report (WEF2008) argued that the surface area of bark nuggets in the biofilters inspected was generally much greater than needed for adequate H_2S reduction and that 99% of odours were removed in the first 25% of media and the next 25% polished the air stream. The media used in a biofilter should be organic high quality premium bark nuggets, homogeneous and well graded, with a particle size between 32 - 55mm (or slightly larger) as delivered on site. Finer particle sizes shall be avoided. Account for bark nuggets breaking apart into finer particle sizes during handling and transport. Care when handling and moving is required. Avoid contamination with aggregate or other materials. Discuss these requirements with the supplier to ensure that the media mix meets CCC's expectations and reduce the risk of premature decomposition and subsequent impedance of air flow. A CCC representative shall inspect and provide formal acceptance or rejection of the media on site prior to placing in a biofilter cell.

Photo: Premium bark nuggets, homogeneous and well graded, with a particle size between 32 and 55 mm

The addition of 15-20% crushed mussel shells to the bark media is recommended to counter highly acidic sites, provided that the distribution line design prevents the holes becoming blocked over time. Shells are considered more appropriate as the binding proteins in the shells limit the migration of the breakdown products, reducing the tendency to block the pipe holes. Shell size "13 Plus" is appropriate as illustrated in the photo below.

Photo: Shell size “13 Plus” (ie. >= 13 mm)

The media should NOT include limestone (calcium carbonate) as the WEF report found that breakdown products may block the holes in the air distribution pipes in high H2S conditions.

The media should NOT include compost as it has been found that compost breaks down rapidly leading to clogging of the bed and high back pressures beyond the delivery capability of the standard fans.

The addition of pumice to the media mix has been trialled by CCC. Results of the effectiveness of including the inert high-surface area product and its added longevity to media life is still being assessed.

If fertilisers are required to maintain the correct media pH, detail specifics in the Operations and Maintenance Manual.

7.3 Empty Bed Residence Time (EBRT)

The airflow to be treated and the desired residence time of the device, impacts on the cross-sectional area and the height or depth of the built structure. The dimensions are controlled to provide the design residence time and to comply with these requirements.

H_2S peak to average ratios greater than 1 in 10 pose critical demands on removing the H_2S within the contact time with the media. The real contact time is possibly only 10-15% of the Empty Bed Residence Time (EBRT), because of the difference in the void volume compared with the empty bed volume. To provide security against short-term odours, choose a long EBRT when treating high peak H_2S concentration. Recommended EBRTs are detailed above in Table 6. These are based on a target maximum H_2S loading of 6 g/m^3 of media per day.

7.4 Plenum

The function of the plenum is to distribute the inlet airflow evenly over the whole area of the biofilter, to minimise short-circuiting of the gas. The success of the biofilter depends on designing the distribution manifold and the stone plenum to maintain its ability to distribute the air with minimal rise in backpressure over time.

Factors to be determined in the design and construction of the plenum:

- Membrane liner
- Leachate drainage
- Metalcourse – as well rounded stone graded 25-40 mm
- Air distribution pipe spacing – generally 900mm
- Air distribution pipe size – generally DN100 or DN150 PVC-U
- Air distribution pipe perforation hole size and spacing – See Figure 7.

Membrane Liner: Place a membrane liner below all components of the biofilter to contain any leachate. Ensure the membrane used is chemically impermeable and mechanically strong enough to resist damage during plenum maintenance. This may be best accomplished by detailing two materials: one to provide the impermeable barrier with another above it to provide the mechanical protection.

The leachate membrane minimum thickness should be 500 µm if fully factory produced or 1000µm if site welding is expected such as for the attachment of wall air leakage control flaps, etc.

Leachate Drainage: Provide leachate drainage in the base of the bed. Slope the bed base towards drilled PVC-U piping, placed at 4m centres at the bottom of the plenum. Detail a 200mm minimum depth water trap in the drainage outfall pipe to prevent the escape of odour.

Drain the leachate from the base of the media bed to the sewer. Invert levels in the sewer may constrain the depth of the media bed, making it necessary to construct a portion of the bed above ground where fall is not otherwise available.

The Plenum: Construct the plenum of a material that has a void ratio that allows a consistent airflow across the bed without increasing the back pressure. This should be through using a washed free-draining rounded well graded metalcourse with a grading between 25 and 40mm.

Place the plenum perforated pipe bedding layer of 100mm and then the air distribution pipes, then the air pipe embedment and overlayer such that the perforations are embedded about 300mm. This will give a plenum overall minimum depth of 460mm for DN150 perforated air pipes and 410mm for DN100 air pipes. The rule-of-thumb for perforation depth is not less than 0.8x the horizontal distance from the perforations to the mid-point between adjacent air pipes. In Figure 7 this is 300/371 = 0.81 and the related air flow pattern in the plenum is as shown on the flow net image of Figure 8.

The Perforated Pipe: These pipes are to be drilled in an even symmetrical pattern with **14mm** diameter holes at 10˚ below pipe mid-height as shown in Figure 7 below. Place these lateral pipes at 900 mm spacing.

In the past standard practice in Christchurch City has been 1500 mm spacing but the WEF study of successful biofilters found that spacing of 900 mm was optimum. The WEF study also found that drilled hole sizes 12mm and smaller blocked in high H_2S conditions (>30 ppm average). The blockages are due to biological growths and chemical deposition, as has been observed in the Beach Road biofilter. To mitigate against these growths Council has standardised on PVC-u pipe with 14mm diameter holes. Ensure the hole spacing and losses over the pipe length allow an even air pressure within the distribution pipe network.

Do not include a filter layer between the plenum and the bark media. CCC experience has found only limited build-up of material where a 6mm pea gravel filter has been included but it has greatly impeded the unblocking and rejuvenation of the air pipe perforations.

Do not include a geotextile separation membrane here as these are prone to blinding over when wet.

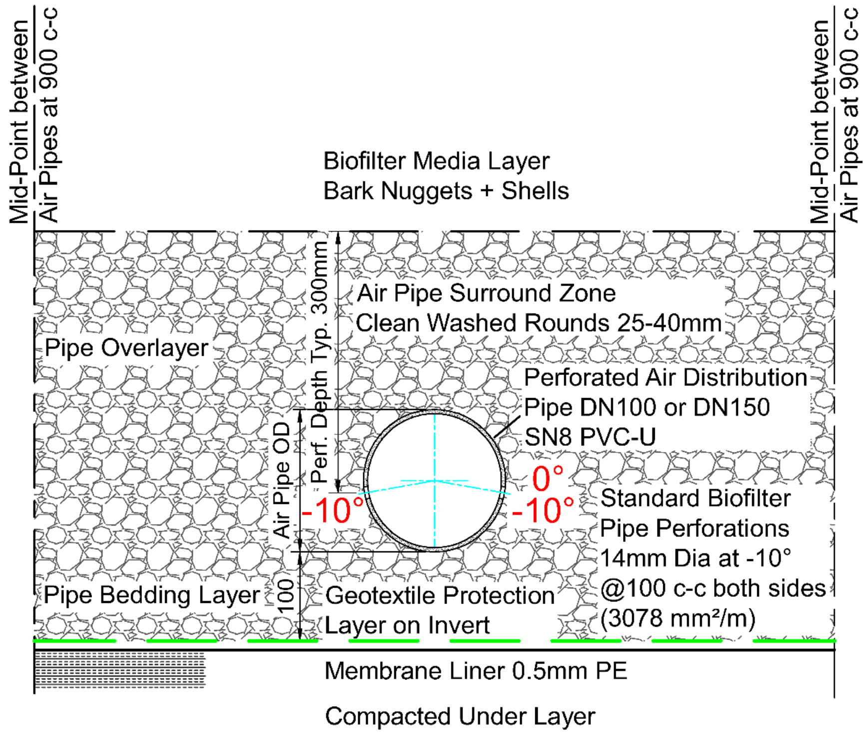


Figure 7: Perforated pipe drilling pattern and pipe placement

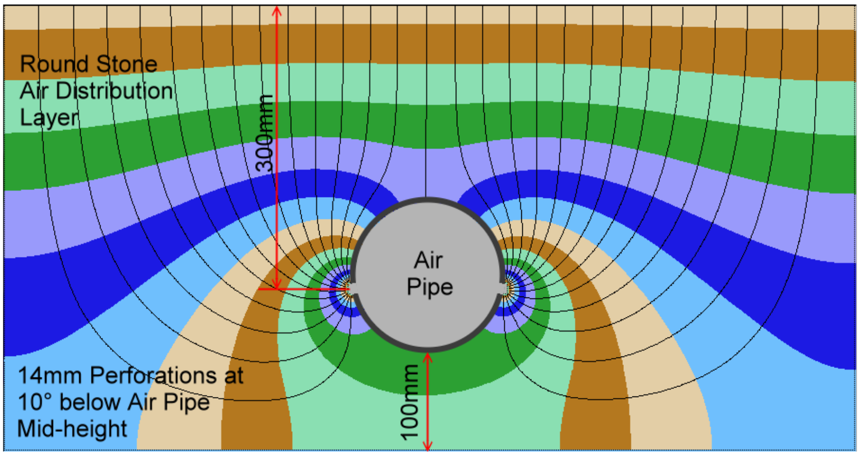


Figure 8: Plenum air flow pattern for DN150 air pipes at 900 centres and 14mm diameter perforations at 300mm below the plenum top surface.

7.5 Biofilter Sizing Example

Below is a worked example for the sizing of a biofilter.

Gravity Pipe Size (ID)	600	mm
Pipe Section Area	0.283	m^2
Half Section Area	0.141	m^2
Air Flow at 1 m/s	0.141	m^3/s
=	141	L/s
cf. PM max discharge	150	L/s
Adopt max air flow above	**150**	L/s
Measured H_2S Mean	**30**	ppm
Peak H_2S	300	ppm
Nearest Residence Distance	20	m
H_2S Mass Flow Rate =	Airflow * AvgH_2S.Conc * H_2S.SG	
H_2S Mass Flow Rate =	150 L/s * 30E-6 * 1.41 g/L	
=	0.0063	g/s
=	548	g/day
=	200	kg/year
Allowable Media Loading	**6.0**	g/m^3/day
So Bed Volume =	(g/day) / Allowable.Loading	
=	548/6	
=	**91**	m^3
Check EBRT =	BedVol/AirFlow	
=	91*1000/150	
=	**644**	sec
This is > 500 sec required for residences < 25m away [See Table 6]		
so 640 seconds EBRT is okay		

7.6 System Airflow Headloss

The determination of system headloss is required in order to determine the air duct sizing and the required air fan performance characteristics. In some cases it may be necessary to extend these calculations along the waste system being vented through to and including the various air inlets.

Site measurement is preferred with the aid of a variable speed suction fan as this removes many of the assumptions relating to the air inlets and friction factors.

It is still useful to calculate airflow rate versus headloss and it is worth doing this ahead of field tests.

For details on calculating headloss see Section 14: “Airflow Headloss Calculation”.

7.7 Air Blower Fan Selection

Factors to be determined are the fan's:

- corrosion resistance (IP rating)
- performance requirements
- noise levels

Polypropylene or PVC integrated fan and motor assemblies are recommended as steel and cast iron materials corrode in H_2S and moist environments. Variable speed drives are required and are essential in higher H_2S situations, to control the loading and avoid odour nuisance during start-up and commissioning.

The air fan should have a rated capacity sufficient to handle system losses including the pipeline conservative suction and pressure losses plus a back pressure from the bed in a deteriorated state of at least 700Pa.

The selected fan shall comply with the site noise constraints. These may be as set out in the City Plan or may be site specific. A physical constraint on the fan blade tip velocity may be required to achieve this as most fan noise arises at the blade tips.

Detail a shielded cable between the motor and variable speed drive where they are separately located, to prevent radio interference in adjacent properties.

7.8 Irrigation

Moisture is essential for the maintenance of a bio-film and the growth of a large range of bacteria, including thiobacillus, in the media. Odour molecules initially diffuse into the water or bio-film layer and are then digested or reduced by the bacteria. Irrigation also aids management of pH.

The primary requirement for irrigation is to maintain the upper half of the biofilter in an evenly moist state (around 65% moisture content). Ensuring the design and installation of the surface sprinkler system provides even and complete coverage is more important than attempting to provide automatic electronic moisture control. Detail both coverage flow rates related to time and the necessary irrigation patterns, to confirm sufficient moisture will be provided.

Irrigation in summer, late spring and autumn can be regulated by a time clock controller with seasonally adjusted 'ON' times. The preferred controller most often used in Christchurch biofilter installations is the Hunter X-Core. Full automatic moisture control (time clock with moisture control override) has been installed on several recent new installations with mixed success. The inherently acidic environment can cause deterioration of moisture sensors and wiring and so failure of automatic systems.

Christchurch sewers are very humid in the cooler months with measurements recording 99% relative humidity. Splash structures installed to deliberately promote the release of dissolved sulphide from rising main discharges produce condensing atmospheres. The moisture levels deep in a biofilter will be moist in most seasons and may be over-wet at times.

No monitoring and recording of moisture levels in sewer reticulation biofilters, to fully evaluate the irrigation options, has been done in Christchurch. Monitoring at the particular installation would quickly provide local data for seasonal settings.

7.9 Water Connection and Backflow Prevention

For the purpose of supplying the irrigation system a metered water connection is required along with a backflow preventer. This also requires application for a new connection. For how-to-do-this refer to Section 10 “Connections”.

7.10 Biofilter O & M Design Considerations

The designer should review the ‘Draft Operation and Maintenance’ section of this guide (Section 11) and the appended O&M check lists for other items that should be allowed for in the design. Also refer to the generic ‘Testing and Commissioning’ text in Section 12.2.

The monitoring schedule should address the required airflow velocity, moisture contents, media pH, backpressure and any other items necessary for the efficient operation of the biofilter.

Note that pine bark has few resident sulphur-reducing bacteria so the media requires an acclimatisation period, possibly four weeks or more, prior to achieving effective odour reduction. Ensure this is considered when assessing the performance after commissioning or provide seeding by mixing in mature bark from an existing biofilter or a quantity of sewage sludge not to exceed 5% of the media composition.

There are many factors to be considered in the design which specifically relate to the operation and maintenance of the biofilter. These include:

- maintenance and machine access including the ease of replacing components
- the ability to clean pipes, their holes and the plenum
- the durability of components
- the frequency of the various maintenance tasks.

Providing riser pipes at the end of each air distribution lateral will facilitate access for cleaning. The pipes, including the leachate drains, can be capped at the surface to allow the entry of medium pressure water blasting equipment.

An access port at the end of the main air distribution manifold is useful for direct air pressure measurement within the manifold free of the dynamic effects of velocity head. A means of achieving this is to add a DN100 pipe extension terminating with an end screw cap. For ease of pressure measurement a ¼” BSP female connector (and plug) should be added to the cap.

Access Port for Air flow rate measurement

An access port must be included on a straight section of the incoming air line for velocity and air flow rate measurement. The type shown in Figure 9 below has been found to be quite useful.

Refer to Section 15 “Air Velocity and Flow Rate Measurement” for basic requirements and guidance on the air flow rate measurement methods. Note that accurate air flow rate measurement is quite challenging.

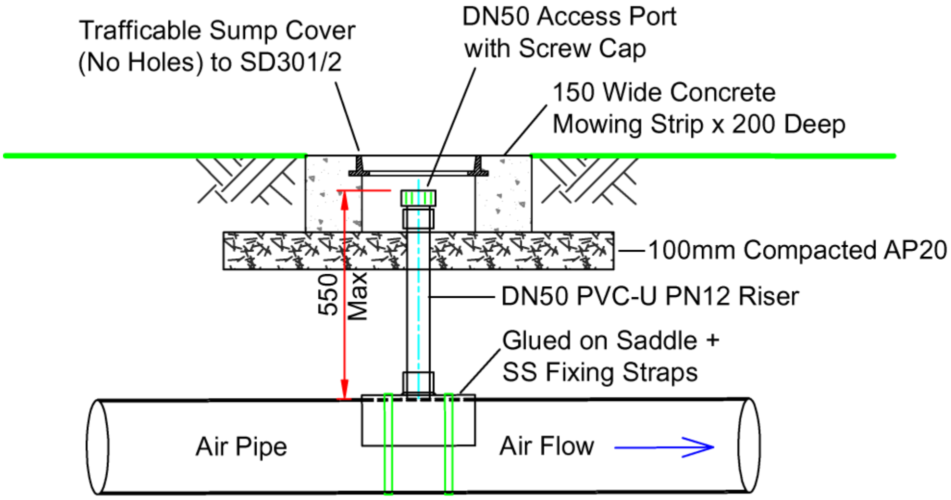


Figure 9: Example access port for air velocity and air flow rate measurement.

Figure 10: Example Biofilter with Battered Earth and Timber Edging

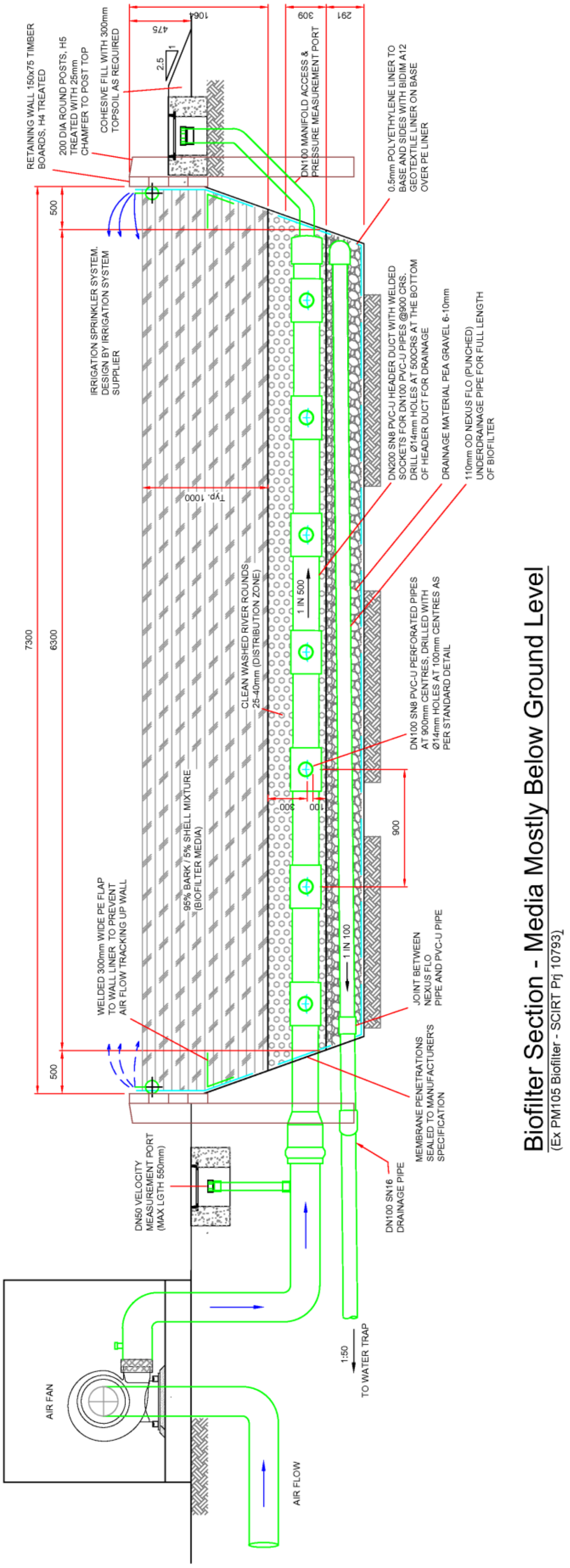
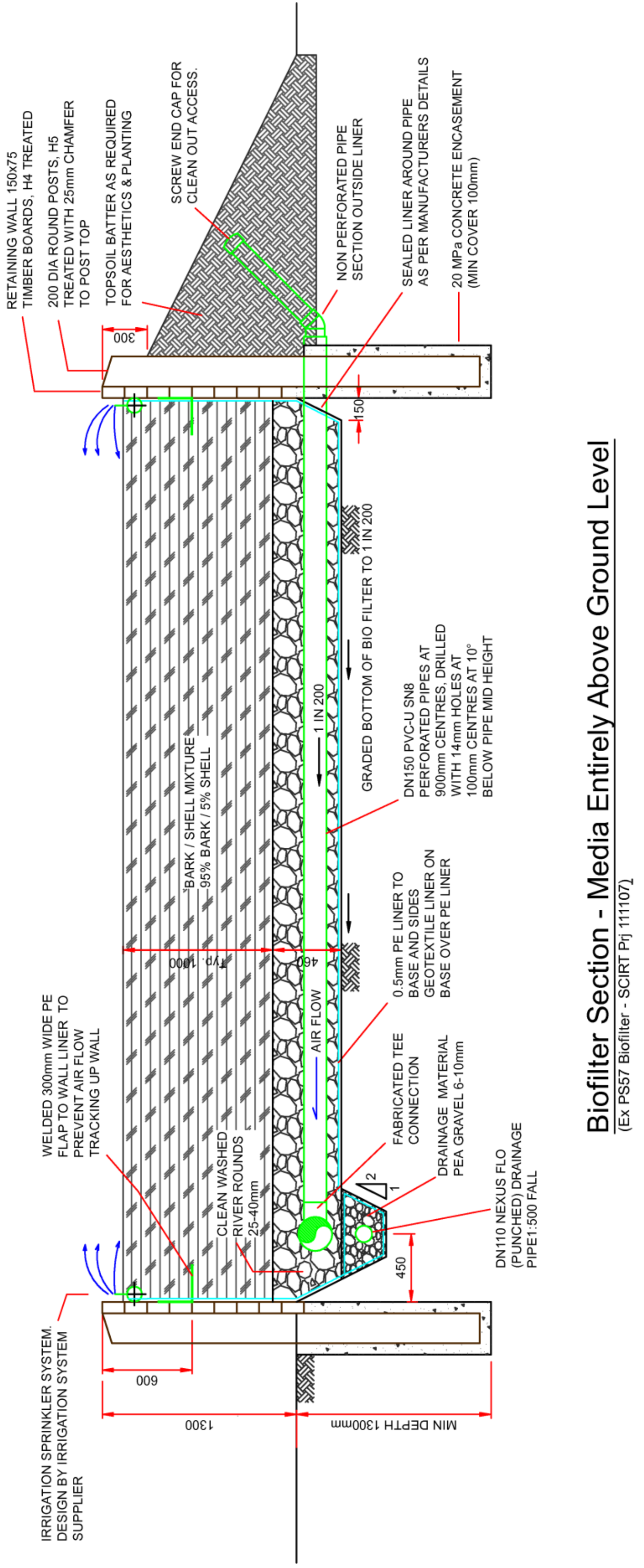


Figure 11: Example Biofilter with Timber Surround [McCormacks Bay PS57]



8 Activated Carbon Filter Design

8.1 Description

Activated Carbon (AC) filters bind the pollutants onto the surface of a solid packing of activated carbon media via adsorption. The media can be impregnated with oxidants, acid or alkaline, to enhance the removal of odorous compounds. The media will become exhausted over time, decreasing its efficiency until replacement is required. The adsorption of compounds by activated carbon is a complex process that depends on a wide range of variables, including:

- Activated carbon properties
- Nature of the adsorbate
- Operating conditions (relative humidity, temperature, pressure, and volumetric flow rate)
- Presence of adsorption competition

The media is enclosed in a vessel that CCC requires to be located above ground. Activated Carbon units require moisture reduction of the incoming odorous air, as the temperature drop across the unit can cause condensation which can clog, damage or inactivate the media. CCC requires forced air flow through the media and a heater unit to keep the media dry.

As a stand-alone technology, Activated Carbon filters are best for low concentration, medium volume applications. They are a simple technology that requires minimal operation and maintenance support, however when treating high volumes or concentrations, a high media replacement frequency is required which may result in an overly large system to meet CCC’s minimum media replacement design standard of five years. They can be used as a polishing stage in conjunction with other odour removal methods, such as a bio-scrubber. When used in this arrangement they provide good management of large peaks and increased assurance that odour removal guarantees can be met.

The effectiveness and mechanisms of Activated Carbon filters to capture common sulphur and nitrogen-based volatiles are provided in Table 9. Refer to the paper (CCC, Feb 2019) for further specific references.

Photo: Western Interceptor Olliviers Reserve Activated Carbon Filter with internal fan and heater. Includes a square concrete base pad extending 200mm beyond the flange base.

Table 9: Common sulphur compound interaction with activated carbon

Substance	*Adsorption Mechanism*	*Final Products*	*Comments*
Sulphur dioxide	■ Physical – on walls and micropore filling. ■ Chemically oxidized after physically adsorbed.	■ Sulphuric Acid.	■ Strongly retained in the pore system, possibly by ionic binding. ■ The greater the degree of oxidation of SO_2 that occurs, the greater the level of SO_2 adsorption.
Hydrogen sulphide – onto virgin AC	■ Physical – on walls and micropore filling. ■ Chemical – onto oxygen-based surface functional groups.	■ Physical – SO_2 and elemental sulphur. ■ Chemical – SO_4^- and elemental sulphur. Further conversion to H_2SO_4 is possible.	■ As a chemical adsorption process, the energy required to extract H_2S is much higher than if it were simply physically adsorbed.
Hydrogen sulphide – onto alkaline or metal impregnated AC	■ Chemical – onto impregnate. ■ Reactive – oxidised using impregnate as catalyst.	■ Alkaline impregnate – sulphite, sulphate, sulphide and elemental sulphur. ■ Metal impregnate – generally elemental sulphur.	■ The oxidation products are non-volatile, and the oxidation is irreversible, so desorption does not occur. ■ Conversion to elemental sulphur is generally preferred as it increased overall H_2S adsorption, however the reaction is slower and requires additional contact time.
Methyl mercaptan	■ Physical – volume filling of micropores and adsorption into monolayers or multilayers on transition pores ■ Under wet conditions, further oxidises to dimethyl disulphide	■ DMDS, sulfonic acid and methane sulfonic acid	■ The adsorption mechanism is pH dependent; however dimethyl disulphide (DMDS) is the common end state. ■ Leads to reduced pH of system.
Dimethyl disulphide (DMDS)	■ Unknown	■ Unknown	■ More strongly adsorbed than water
Dimethyl sulphide (DMS)	■ Physical. ■ Chemical – onto oxygen containing surface groups and acidic groups.	■ Unknown	■ DMS has traditionally been poorly adsorbed in environmental odour control applications.
Carbonyl sulphide	■ Physical. ■ Chemical – multi-metal impregnate acts as catalyst.	■ Multi metal impregnate - sulphate	■ Some studies have observed the reduction in carbonyl sulphide adsorption capacity by AC in the presence of H_2S or carbon disulphide.

Table 10: Summary of activated carbon best practice design parameters

Parameter	*Literature range*
Media moisture content	< 50%. Alternatively, pre-treatment to remove moisture in air required as per CCC requirements.
Media depth	0.9m
Empty Bed Residence Time (EBRT)	> 3 seconds
Temperature	15- 40°C
pH	Not required

8.2 Media moisture content

For the removal of VOCs, water vapour shall compete for adsorption sites on the surface of the activated sites, hence ensuring low relative humidity (RH) on the inlet stream should be attempted for efficient removal. Below 50% RH was found to have no significant effect on carbon filter service life. However, above 65% RH was found to severely compromise filter performance. Maintaining an upper bound < 50% RH is recommended for the influent gas stream in other literature.

Specifically, for H_2S the opposite relationship is observed with humidity significantly increasing the adsorption capacity. The adsorption capacity at dry conditions is often very small and is mainly due to physical adsorption; a high level of humidity in the gas stream is necessary for adsorption of H_2S via oxidation and chemical adsorption. Literature states that between 10–60% for H_2S adsorption by activated carbon having basic functional groups or basic catalysts. Humidity also enhances methyl mercaptan (CH_3SH) adsorption by initially facilitating the dissociation of CH_3SH into dimethyl disulphide which is then adsorbed onto the carbon surface. Carbonyl sulphide adsorption is however reduced as relative humidity increases in the presence of H_2S in the gas stream.

8.3 Media depth

Media depth is limited to generally less than 1m, due to the risk of the weight of carbon crushing the media beneath.

8.4 Empty Bed Residence Time

For a given bed volume, the volumetric flow rate affects the removal efficiency via the contact time allowed for adsorption to occur. Increasing the contact time increases the probability that the adsorbate molecules reach the adsorption sites with design values of 1–3 seconds are typically used. The empty bed contact time is not theoretically or mechanistically based and is instead based on experience or pilot scale studies. The empty bed residence time shall be based on an airflow velocity equivalent to 1 m/s for a half-filled pipe so that corrosion control in the pipeline is also achieved.

8.5 Temperature

Adsorption capacity decreases as the temperature within the adsorbent bed increases due to increased adsorbate vapour pressure and adsorbed molecule energy level. This leads to a portion of the adsorbed molecules gaining sufficient energy to overcome the weak van de Waal's attraction and returning into the gas phase (effectively desorbing).

8.6 Media Life

The activated media volume is to be sufficient for a media life of five years between media maintenance replacement events.

8.7 Activated Carbon Filter Sizing Example

Below is a worked example for the sizing of an Activated Carbon filter.

Gravity Pipe Size	300	mm
Pipe Section Area	0.071	m^2
Half Section Area	0.035	m^2
Air Flow at 1 m/s	0.035	m^3/s
=	35	L/s
cf. PM max discharge	55	L/s
Adopt max air flow	**55**	L/s
Measured H_2S Mean	**2.4**	ppm
H_2S Mass Flow Rate =	Airflow * AvgH_2S.Conc * H_2S.SG	
=	55 L/s * 2.4E-6 * 1.41 g/L	
=	0.00019	g/s
=	16	g/day
=	5.9	kg/year
Required Media Life	5.0	years
Rqd Lifetime H_2S Adsorption	29.3	kg
Media Adsorption Mass%	**25%**	
So, Media Mass Required =	**117**	kg
Check Media Contact Time:		
Media Density =	500	kg/m^3
Media Volume =	0.235	m^3
Contact Time =	MediaVol/AirFlowRate	
=	0.235*1000/55	
=	4.3	sec
This is > 3 sec min EBRT [Table 6] so is okay		
Sizing to be confirmed by the system supplier based on the required air extraction rate and mean and max H_2S values above. Also assume the air stream is 100% saturated and at 12°C		

8.8 System Airflow Headloss

The determination of system headloss is required in order to determine the air duct sizing and the required air fan performance characteristics. In some cases it may be necessary to extend these calculations along the waste system being vented through to and including the various air inlets.

Site measurement is preferred with the aid of a variable speed suction fan as this removes many of the assumptions relating to the air inlets and friction factors.

It is still useful to calculate airflow rate versus headloss and it is worth doing this ahead of field tests.

For details on calculating headloss see Section 14: “Airflow Headloss Calculation”.

8.9 Site Layout and O & M Design Considerations

The Activated Carbon unit siting should be such that that there is good vehicle access for removal and replacement of media, generally using a sucker truck.

Siting must consider sound noise levels and comply with City Plan noise limits.

The facility must have a detached switchboard in a cabinet with an easily accessed isolating switch independent of any switch built into the unit by the supplier.

For a typical Activated Carbon site the power box and switchboard cabinet should be against the boundary and adjacent to the internal common boundary but clear of a driveway for least impact on the adjacent resident.

For the typical site layout see Figure 12 below.

See also Section 10.2 “Electrical Connection”.

Activated carbon units must be fitted with a silver dipstick so that the rate of activated carbon consumption can be measured. The silver dipstick must be easily accessible with minimal effort for efficient maintenance monitoring.

An access port must be included on a straight section of the incoming air line for velocity and air flow rate measurement. Refer to Section 15 “Air Velocity and Flow Rate Measurement” for basic requirements and guidance on the air flow rate measurement methods. Note that accurate air flow rate measurement is quite challenging.

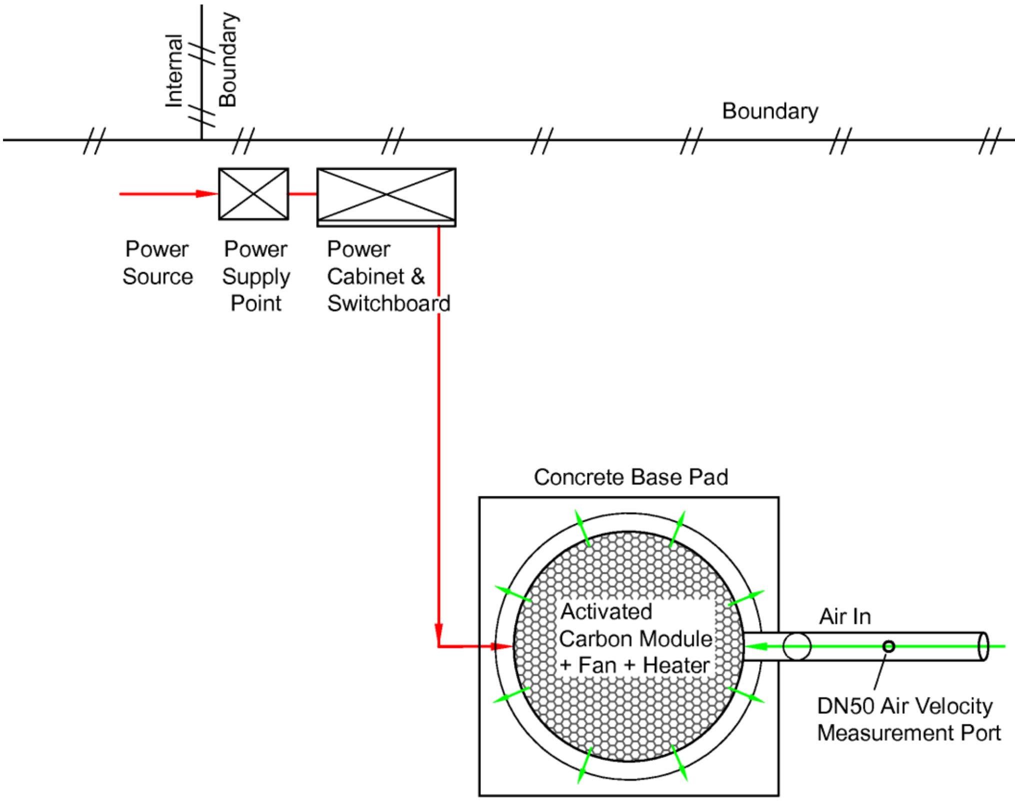


Figure 12: Typical Activated Carbon Site Layout. Note that the power box and switchboard cabinet should generally be against the boundary and adjacent to the internal common boundary.

8.10 Air Valve Odour Treatment

Where Air Valves create an odour nuisance Council may require the addition of an odour treatment system – generally as a passive Activated Carbon filter.

There are some complicating scenarios that such system may have to allow for. These include:

Air Valve Leakage: Where the pressure main static head is less than 2m air valves often do not fully seal so tend to weep. Such locations require seepage flow interception between the air valve and the odour filter with seepage discharged to the local gravity reticulation via a water trap. Back pressure from an AC filter is generally quite low (typically < 50mm) so prevention of air discharge down the drain line can be managed by including an accessible water trap with at least 300mm water depth. An example installation is on PM31 outside Re Raekura Redcliffs School as illustrated in the schematic below.

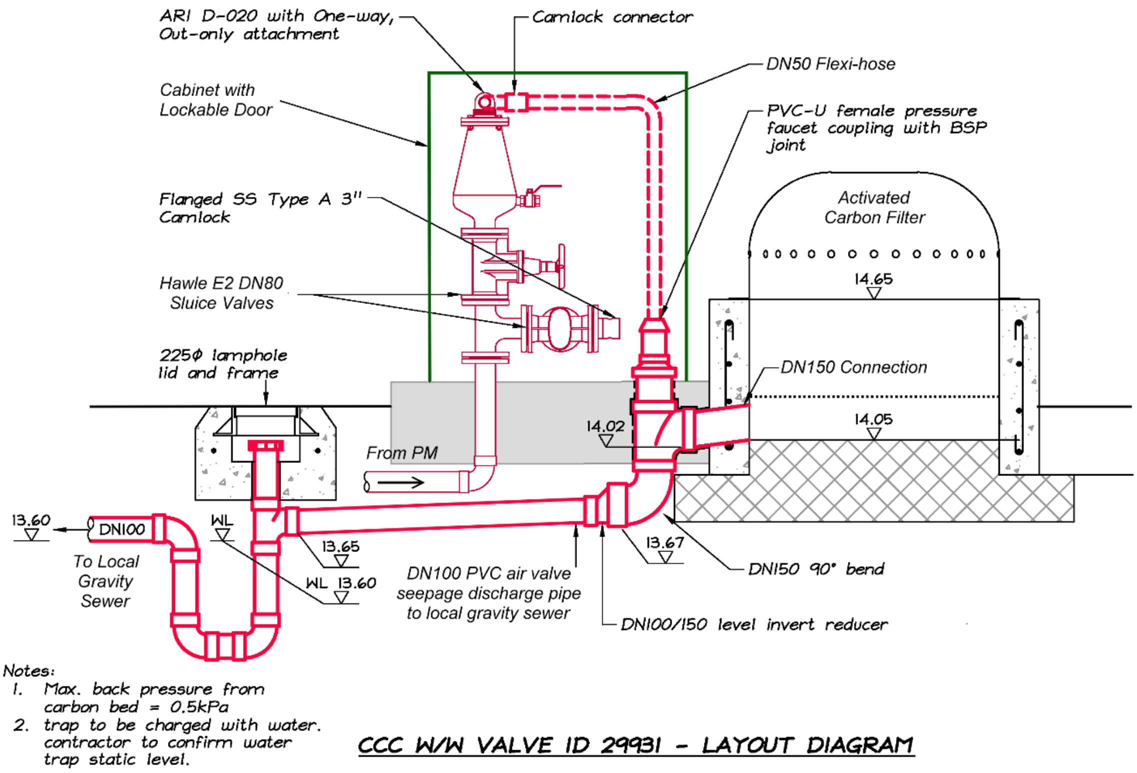


Figure 13: Airvalve with passive odour treatment and a seepage drain outlet

High Airflow Rate: Where the Air Valve air flow is bi-directional, and high air flow rates are essential for transient suppression, the design is rather more challenging as pressure relief flaps may have to be included that allow the high air flow rate to bypass the odour filter. There is no example as yet but one is proposed for installation on PM11B on Randolph St. For this site noise suppression is a further design criterion.

9 Bio-Scrubber Design

9.1 Description

Bio-scrubbers (sometimes referred to as stacked biofilters or trickling filters) comprise of a vessel of packed plastic media bed populated with microorganisms. Similar bio-chemical reactions occur as in biofilter, but within an enclosed vessel and therefore under controlled conditions.

The key feature of bio-scrubbers (compared with biofilters) is that the environment within the bio-scrubbers can be controlled. Bio-scrubbers have an irrigation system to keep the media moist. They also have nutrient dosing to maintain a healthy microbial population. This enables them to operate at higher loading rates than biofilters and to provide more consistent and efficient removal of odorous compounds. They are also generally robust though shock loading from highly variable wastewater streams containing extremely high H_2S concentrations.

Bio-scrubbers have the following advantages:

- Low operating costs;
- High efficiency
- Low environmental impact
- Low empty bed residence time required (EBRT) (thus lower footprint);
- Low head loss even at higher gas velocities;
- Control of the operating parameters (pH, nutrients, temperature and accumulation of toxic metabolites) for process optimisation.

Photo: Clifton Bio-scrubber – Station ID: OC0491

Bio-scrubbers are generally modular and additional modules can be installed as required should the load increase. They can be configured as a single parallel bed arrangement or twin (2-stage) beds in series. Twin beds arrangement allows the internal environment to be varied, thereby creating different operational zones. These zones can be optimised to target autotrophic (treatment of H_2S) bacterial growth (as the first stage) followed by heterotrophic (treatment of VOC, mercaptans) as the second stage. This improves the overall process robustness and allows a wider range of odorous compounds to be removed. A more detailed description of the chemical processes involved can be found in 'CCC, Feb 2019'.

Airflow can be drawn through the system using a fan on the outlet, minimising equipment in contact with the odorous and corrosive gas. The configuration can be vertical or horizontal.

Bio-scrubbers are enclosed and therefore they are less susceptible to disturbance from environmental conditions such as rainfall and low humidity. Bio-scrubbers generally have a compact footprint due to a taller bed height and shorter residence time compared to biofilters. This however may cause the Bio-scrubbers to be visually detrimental, particularly at sites with high air flow rate, which require large diameter or tower height. Due to the nature of the microorganisms involved, they perform best with a stable input concentration but generally perform well with occasional shock loading. Large peaks in concentration can upset the microbial process and may cause odour breakthrough events. For this reason, bio-scrubbers are commonly followed by a carbon adsorption unit polishing stage to treat odour peaks, especially in urban or other sensitive areas. In extreme cases, the microbial population can be killed off by such large peaks or toxicity from trade waste discharges. Similar to biofilters, it takes time for the microbe colony to develop (or re-develop) and it can take several weeks to become fully operational. The table below provides a summary of bio-scrubber design variables.

Table 11: Summary of bio-scrubber best practice design parameters

Parameter	*Literature range*
Media moisture content	Liquid circulated in media
Media depth	1-5 m
Empty Bed Residence Time (EBRT)	> 10 seconds
Temperature	5-45 °C
pH	~pH 2.5 for autotrophic region ~pH 7 for heterotrophic region
Carbon adsorption unit (EBRT)	> 5 seconds

9.2 Media Moisture Content

Trickling liquid is sprayed onto the media and periodically dosed with a Nitrogen Phosphorous Potassium (NPK) liquefied fertiliser solution based on monitored concentrations of pH, nutrients and salt in the fluid. The liquid is directly responsible for the moisture levels inside the bio-scrubber effecting mass transfer of the pollutant to the biofilm and maintenance of the health of the biofilm.

9.3 Media Depth

Media depth correlates to tower height, and also flow rate of air. The recommended minimum height is 1 m to allow sufficient EBRT without excessively slow flow rates. Height is often limited by pressure drop across the filter (fan sizing to provide air flow for the length of the filter to achieve a design standard minimum airflow velocity of 1 m/s in a half-filled pipe), or other non-design variables such as visual impact.

9.4 Temperature

Operating temperature plays a significant role as it has a direct effect on the following:

- Diffusion coefficient
- Absorption rate
- Kinetics of biodegradation.

9.5 pH

pH can often vary as a result of biological activity and metabolic digestion pathways. Both H_2S and mercaptans (under certain pathways) are digested (oxidised) to form H^+ ions which lower the pH of the solution, and hence biological activity if these acidic products are not removed or adjusted. In research conducted by Hernandez et al., H_2S and Ethyl Mercaptan (EM) took 7 and 10 days respectively in the pH-controlled bio-scrubber to reach a removal efficiency above 95%. This was significantly lower than the time needed in the uncontrolled bio-scrubber, which lasted 14 and 26 days, respectively.

9.6 Water Connection and Backflow Prevention

For the purpose of supplying the trickling fluid replacement water a metered connection is required along with a backflow preventer. This requires application for a new connection. For how-to-do-this refer to Section 10.1 "Water Connection".

9.7 Bio-Scrubber Sizing Example

Below is a worked example for the sizing of a bio-scrubber.

Gravity Pipe Size	600	mm
Pipe Section Area	0.283	m^2
Half Section Area	0.141	m^2
Air Flow at 1 m/s	0.141	m^3/s
=	141	L/s
cf. PM max discharge	150	L/s
Adopt max air flow	**150**	L/s
Measured H_2S Mean	**30**	ppm
Peak H_2S	**300**	ppm
H_2S Mass Flow Rate =	Airflow * AvgH_2S.Conc * H_2S.SG	
H_2S Mass Flow Rate =	150 L/s * 30E-6 * 1.41 g/L	
=	0.0063	g/s
=	548	g/day
=	200	kg/year
Allowable Media Loading	**240**	$g/m^3/day$
Target EBRT =	15	
Required Media Volume =	Airflow * EBRT	
=	150 /1000 * 15	
=	**2.3**	m^3
Housing Volume =	Media Vol * 4	
=	9.2	m^3
Assume Cabinet Hgt= Width = Lgth/2 => Width = (HousingVol/2)^$^{0.333}$		
So Approx Hgt and Width =	1.7	m
and Length =	3.3	m
Actual Sizing to be provided by the system supplier based on the required air extraction rate and mean and max recorded H_2S values.		

9.8 System Airflow Headloss

The determination of system headloss is required in order to determine the air duct sizing and the required air fan performance characteristics. In some cases it may be necessary to extend these calculations along the waste system being vented through to and including the various air inlets.

Site measurement is preferred with the aid of a variable speed suction fan as this removes many of the assumptions relating to the air inlets and friction factors.

It is still useful to calculate airflow rate versus headloss and it is worth doing this ahead of field tests.

For details on calculating headloss see Section 14: “Airflow Headloss Calculation”.

9.9 Site Layout and O & M Design Considerations

The Bio-scrubber siting should be such that that there is good vehicle access for the regular replenishing of the dosing solution and removal and replacement of media with a sucker truck from the activated carbon polishing stage.

Siting must consider sound noise levels and must comply with City Plan noise limits.
The facility must have a switchboard with an easily accessed isolating switch. If not easily accessible then there should be a separate switchboard and cabinet with this and the power box against the boundary and adjacent to the internal common boundary but clear of a driveway for least impact on the adjacent resident.

For the typical Bio-scrubber site layout see Figure 14 below.

See also Section 10.2 “Electrical Connection”.

The Bio-scrubber Activated Carbon polishing unit must be fitted with a silver dipstick so that the rate of activated carbon consumption can be measured. The silver dipstick must be easily accessible with minimal effort for efficient maintenance monitoring.

Access Ports for air flow rate measurement: An access port must be included on a straight section of the incoming air line for velocity and air flow rate measurement. Refer to Section 15 for basic requirements and guidance on the air flow rate measurement methods. Note that accurate air flow rate measurement is quite challenging.

Initial Operation and Optimisation

The product supplier is to commission and operate the unit for a contracted period of time to troubleshoot and resolve teething issues and optimise its operation as is standard practice for newly commissioned wastewater treatment plants.

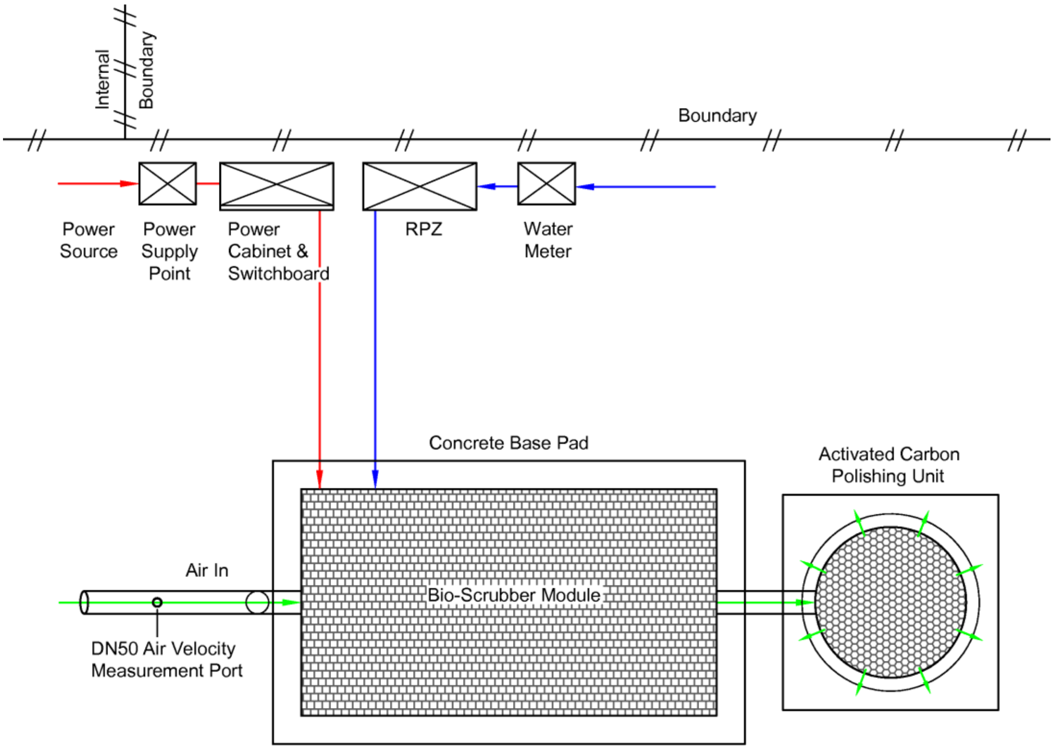


Figure 14: Typical Bio-scrubber Site Layout. Note that the power box and switchboard cabinet should generally be against the boundary and adjacent to the internal common boundary.

10 Connections – Water and Electrical

10.1 Water Connection

For those sites requiring a water supply, including biofilters and bio-scrubbers, a metered connection is required along with a, RPZ backflow preventer complying with the details shown on CSS SD421. This also requires application for a new connection using Form WS1 on Council's 'Connections' web page along with adherence to the backflow prevention requirements found by following the link on the same web page.

10.2 Electrical Connection

The electrical connection and switchboard shall be to the Council standard requirements as below.

- The site power connection is to be arranged with Orion.
- Energy metering is required for all sites unless a low energy usage exemption is approved by the Energy Supplier.
- The Energy supplier shall be Council's small site energy supplier. Obtain this name from Council via an email to: energymanagement@ccc.govt.nz.
- Obtain the site ICP number from the energy supplier and send this to Council as soon as the site is made live to ensure that payments are assigned to the correct asset. Send this to the Energy Management email address above.
- The Switchboard shall be manufactured to the CCC Standard Odour Control Station switchboard design. Refer to the CCC standard Odour Control Station electrical drawings.
- The switchboard cabinet shall be the CCC standard odour control cabinet size and type as noted on sheet E02 of the standard Odour Control Station electrical drawings. The standard cabinet size is 1400mm height above ground level x 785 wide x 310 depth.
- Where there is an adjacent private property boundary then the switchboard cabinet should generally be located against the boundary and also to one side of the property adjacent to the common internal boundary. See the site layout diagrams in Sections 8 and Section 9.

Where power is supplied from an existing Council facility switchboard (eg. at a pump station) then a separate switchboard is generally not required.

11 Operations and Maintenance Manual

A ’Draft’ O & M manual is required at design completion written by the system designer as the person most familiar with design objectives and the intended design operation. This draft manual will also provide the basis for system commissioning and will greatly simplify the completion of the final O & M manual and its early delivery to the Asset Owner.

The ‘Final’ O&M manual will be based on the draft manual but will include the as-built drawings plus the commissioning observations, plus photos, etc.

The O&M Manual must include a cover page with site photo and a heading including the site name and Station Number, followed by the report contents under headings including items described below in Sections 11.1 to 11.8.

11.1 Purpose

The manual should detail all the pertinent information and data necessary to:

- Understand the operation and maintenance of the system as a whole and the various components that make up the system.
- Specify how the system should function as designed.
- Specify how the system should be operated and maintained.
- Provide reference information on all major items of equipment.

11.2 Overview

Briefly describe the physical attributes of the site and system, including the objectives of the treatment option, why it is required, where it is located and how it fits into the existing infrastructure.

11.3 System Design

Include all design parameters and any assumptions upon which they are based. Provide sufficient information to allow the design conclusions to be replicated. These details could be provided by including the design report for the project.

For a biofilter the stated parameters will include the bed surface area, the filter media make up and depth, media volume, media void ratio, media air flow porosity, airflow rates, moisture content, temperature, pH, normal operation back pressure, ventilation rate and the EBRT.

Highlight issues that are crucial to the operation of this site or that had a particular influence on the system selection and/or design.

Include completed commissioning checklists and test results, with operational parameters determined through commissioning.

Include asset registers and as-built plans.

11.4 Monitoring

The most important part of improving any treatment system's design and performance is a very good source of performance monitoring data as this provides a means of early fault detection or media end-of-life through mapping trends and can highlight possible problems and maintenance requirements.

The O&M Manual should detail items to be monitored, their importance and the frequency. This is likely to include monitoring of specific items at various frequencies including: monthly, bi-monthly, annual, two yearly, and five yearly intervals.

The O&M Checklists appended to this Guide provide some guidance in monitoring items but further items should be added as required that relate to the design parameters as detailed in the Operation and Maintenance manual.

The monitoring results should be presented as a report to the Asset Owner and should detail what happens to the monitoring results and who is responsible for carrying out which aspects of the monitoring plan.

The monitoring report should also highlight required maintenance work.

Some monitoring will require auditing by Water and Waste Staff e.g. a visual inspection of the base of the media bed when a biofilter is being turned over, to assess the remaining life. Ensure these requirements are noted in the Operation and Maintenance manual.

For biofilters the monitoring must include an assessment of the media's condition over time at multiple depths as the reduction in condition and media particle size over time provides a clear indication of the media's decomposition and the need for maintenance.

11.5 Troubleshooting

Provide a guide for action if the values specified in the monitoring checklist are not achieved. This should relate to the maintenance schedule also.

11.6 Maintenance Schedule

Maintenance is carried out to ensure the system operates as designed. This will remove the potential for odour complaints and reduce corrosion in the pipework. Ensure safety requirements are incorporated as part of the maintenance manual.

Detail items to be maintained, their importance and the frequency. Relate to monitoring results where applicable. Include an O&M schedule based on those appended to this guide adapted to the site as necessary. Items should include a Task / Frequency list. For example:

Task Description	**Frequency**
Weed biofilter media bed	eg. monthly
Measure & record the airflow rate	eg. annually

11.7 O&M Records

State what records are generated and where they will be stored or what action they will generate. This might for example include a record of the dates of any maintenance work and issues found. eg. the degree of distribution pipe perforation blockage, the depth and condition of media.

11.8 O&M Manual Appendices

O&M Manual Appendices should include at least the following:

- Installation Manual
- Monitoring Checklist
- Maintenance Schedule
- Local area sewerage reticulation map
- As-built plans
- Photos including:
    - Site photo
    - Fan photo
    - Motor name plate photo
    - Controls photo
- Equipment manuals (i.e. fan, variable speed drive, heater, etc.)
- Instrumentation data sheets

12 Construction and Commissioning

12.1 Construction

Keep an accurate record of the final construction and commissioning details to complete the full as-built record. This will also allow a later design performance review.

The IDS Clause 12.4.3: “As-Built Records” expands on the information required. Records of the constructed assets required, to support future monitoring and assessment, include:

Asset Register:

- the asset register with details of all specified assets

Air Intake System:

- Fan make, model, speed (rpm)
- Variable speed drive make, model, frequency setting (Hz)
- Pipe diameters and materials.

Biofilters:

- Media: Date of installation
- Media: Bed dimensions (m x m), and area (m^2)
- Media volume (m^3)
- Media depth (mm) of each layer to below the distribution pipe.
- Separation layer
- Type of dispersing layer
- Distribution pipe material, spacing and diameter. If drilled PVC, include diameter, spacing and layout of drilled holes
- Media details – type, composition, % fines, pH, moisture content, *in situ* density
- Irrigation system details, timer settings, coverage of irrigation system (%)
- Horizontal air leakage barrier

Activated Carbon Filter:

- Date installed
- Make and model
- Heater unit
- Activated media type
- Media volume
- Container type (bulk, cartridge, etc).

Bio-scrubber:

- Date installed
- Make and model
- Media type

- Dosing solution
- Dosing tank volume
- Dosing rate
- Activated carbon filter (polishing unit) as specified above.

Electrical:

- CCC Electrical Rep Inspection and Signoff
- ICP# as provided by the energy supplier. This must be supplied to Council as soon as the site is made live along with the Odour Control station number and address. Send to: energymanagement@ccc.govt.nz

12.2 Testing and Commissioning

Prior to commissioning the system designer must prepare the Draft Operation and Maintenance Manual including the collation of the as-built records. From this a 'Commissioning Checklist' must be produced based on the Draft O&M Manual and the O&M checklists.

Testing and commissioning is intended to prove either that both the design and its related performance parameters are attainable and appropriate or to provide adjusted parameters that will fulfil the design and so achieve the objectives of the installation.

To this end, specific tests or measures should be detailed that will satisfy the objectives detailed under Section 3 “Objectives” and written into the 'Draft Operation and Maintenance Manual' along with the 'Design Statement' and design parameters. For example, the system attains the parameter, “achieving the specified infrastructure design life by preventing future deterioration of current or future assets” through H_2S concentration measurements below the stated threshold.

Tests to be carried out could include:

- Airflow measurement. (See Section 15: “Airflow Velocity and Flow Rate Measurement”)
- Gas concentrations
- Smoke test to confirm inflow at air inlet vent or vented manhole
- Backpressure and headloss measurements.

Mechanical and Electrical items to be assessed as part of this process, to ensure their function, may include:

- Fan operation
- Heater operation
- Irrigation system performance
- Electrical inspections

If operational issues become apparent during commissioning then an extended period of more frequent monitoring may be required.

Records from the first performance monitoring should be appended to the O&M manual and the manual amended or extended as required to become the finished handover document.

13 Hand Over

The Handover process ensures that a complete and functional system is received by the Council Asset Owner along with sufficient records for inclusion in Council's Asset Management System and subsequent participation by Council's Maintenance Contractor.

The Handover process to be followed for any new odour control site is detailed in the '*Project Handover Procedure Flow Chart'* (CCC, 2018), and the related check lists.

Items include:

- The Odour Control Station ID. *(Should have been obtained from the Asset Management Team during the design phase).*
- Documenting the electrical supply ICP number. *(Should have been supplied to Council during the construction phase. See Section 12.1: "Construction").*
- *The electrical certificate(s) of compliance.*
- Completion of the asbuilts.
- Completion of the O&M manual.
- Site inspections by the Asset Owner and Maintenance Contractor.
- Item formal signoffs.
- Acceptance by the Operations Team.
- Acceptance by the Asset Management Team, and
- Acceptance by Council's Maintenance Contractor.

14 Airflow Headloss Calculation

14.1 Simple Conduit Airflow Headloss Calculation

A calculation of system headloss is required in order to determine the air duct sizing and the air fan performance characteristics. In some cases it may be necessary to extend these calculations along the waste system being vented through to and including the various air inlets.

Air flow calculations can be complex when changes in air density due to altitude, suction, compression or temperature are included as well as water flow induced air flow.

For Christchurch odour filters however the pressure variations from standard sea level atmospheric pressure are small such that the head loss calculations can be based on a standard pressure of 101,300 Pa and a temperature of 15°C. In general air extraction should draw air in the same direction as the wastewater flow. If unavoidable then drawing air against the flow direction should only be considered for subcritical flow with a Froude Number less than 0.6 because waves induced in high subcritical and supercritical flow create problematic and indeterminate head losses.

For a water flow Froude Number less than 0.6 the water flow induced drag is negligible so the air duct pressure loss calculation is then reduced to the simple duct headloss formula below.

dp = (0.019 * Q^1.9 / de^5.02) * Length (Pa) - Eqn 1

where:
dp = duct pressure loss (Pa)
de = equivalent duct diameter (m) ≈ (4A/π)^0.5 - Eqn 2
Q = air volume flow (m^3/s)
Length = air duct length (m)

In addition there will be inlet, outlet, bend and fitting losses. These can be allowed for as loss coefficients multiplied by air velocity head where velocity head is calculated as:

Dynamic Pressure: P_D = ρa * vel^^{2}/2 (Pa) - Eqn 3

where:
ρa = Air Density: (1.225 kg/m^3 @ 15 °C)
vel = velocity (m/s)

The following parameters represent friction loss constants (equivalent pipe lengths (m)) which are required for calculating total head loss (see following example calculation).

Inlet loss coeft typ (k_{in}) :	0.25
Outlet loss coeft typ (k_{out}):	1.0
Sharp 90 degree bend :	1.3
Swept 90 degree bend:	0.5
Sharp 45 degree bend :	0.5
Swept 45 degree bend:	0.2

An example calculation is:

Flow: Q = 0.080 (m^3/s)
Dia: de= 0.150 (m)
Pipe Lgth: L = 50 (m)

Pipe Area: $A = de^{\wedge 2} * Pi/4 = 0.0177$ (m^2) - Eqn 4
Velocity: vel = Q/A = 4.52 (m/s) - Eqn 5

Air Density: $\rho a = 1.225$ (kg/m^3)
Dynamic Pressure: $P_D = \rho a * vel^{\wedge 2}/2$ (Pa)
= 12.5 Pa

Pipe friction loss: $dp = (0.019 * Q^{\wedge 1.9} / de^{\wedge 5.02}) * L$ - from Eqn 1
$= (0.019 * 0.080^{\wedge 1.9}/0.150^{\wedge 5.02}) * 50$
= 107 Pa

Total head loss: $HLTotal = (k_{in}+k_{out}) * P_D + dp$ (Pa) - Eqn 6
= (0.25+1.0) *12.5 + 107
= 122 Pa

Water Flow Induced Air flow and Headloss

Where extraction of air against the flow direction is unavoidable and the Froude Number exceeds 0.6 then it is necessary to add an allowance for the increased air/water interface flow drag. This can be allowed for as an approximation by calculating the induced air flow in the pipeline due to water surface induced drag using the empirical relationship of Pescod and Price (1982), then adding this to the basic air flow rate, then using this modified air flow rate to determine the required fan operating speed.

In summary the procedure is:

- Calculate the pipeline suction headloss assuming zero water velocity.
- Add on the treatment system headloss to get 'Total Fan head'.
- Calculate the pipeline water flow induced air flow rate using Pescod's formula.
- Add this induced air flow rate to the basic design air flow rate assuming zero water velocity.
- Assess the fan operating curves based on this higher air flow rate and 'Total Fan Head'. ie. The fan speed/differential head operating point and required power.

The final fan speed must be adjusted on site to achieve the required basic air flow rate with flow levels and flow rates matching the design scenario.

$V_{air} = 0.397 * (W * V_W / P_{air})^{\wedge 0.723}$ Pescod's formula - Eqn 7

where:
V_{air} = average headspace velocity (m/s)
W = water surface width (m)
V_W = water velocity (m/s), and
P_{air} = headspace (unwetted) pipe perimeter (m)

For a pipe flowing half full the air flow induced velocities are as tabulated below. Over the range shown the water surface roughness equates to 50-67% of pipe wall roughness, increasing with water velocity.

Table 12: Water flow induced air velocity in a half full pipe

Water Velocity (V_w)	*Air velocity (V_{air})*
0.5 m/s	0.17 m/s
0.6	0.20
0.8	0.24
1.0	0.29

14.2 Airflow through a Wastewater Main with Multiple Air Inlets

Airflow determination for a wastewater main with multiple air inlets can be assessed by summing inflows and vacuum increments from the network elements such as for the simple network layout shown in Figure 15 below. This solution will generally require iteration to arrive at the desired total air extraction rate or the required suction vacuum pressure.

Alternatively do a field measurement of air extraction rate versus vacuum pressure while also measuring the vacuum pressure and air draw rate at the target primary air inlet site.

The analytic procedure is to set up an Excel spreadsheet to sum the incremental vacuum pressures along the primary air flow path while adding in airflows from the primary air inlet and from each lateral based on the vacuum pressure at each lateral/main junction. Then, using Excel's "Goal Seek" iterative solver, set either the extraction air flow rate cell, or the extraction vacuum pressure cell, to the required target value by changing the primary air inlet air flow rate cell.

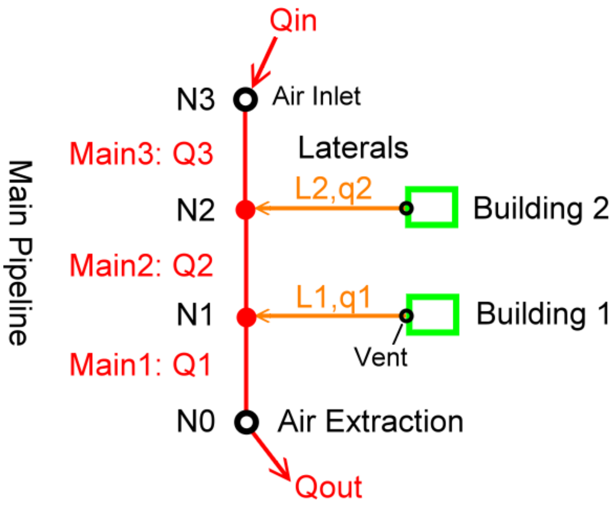


Figure 15: Simple pipe network schematic

Main pipe equivalent diameter when running half full:

Apipe = Pi*ID^2/4 where ID is the pipe internal diameter
and: Aair = Apipe/2 where Aair is the pipe air space area when running half full
Pipe equivalent diameter (de) = (4A/Pi)^0.5 (approx)

So: de = D/Sqrt(2) = 0.71 * ID where the air space is half the full pipe area

Determining a duct vacuum pressure drop for a target air flow rate
For a wastewater main, the vacuum pressure drop "dp" (Pa) required to draw air flow "Q" (m3/s) through a pipe of effective diameter "de"(m) and pipe length "Lgth" (m) is a function of parameters *(Q,de,Lgth)* and may be calculated from Eqn 1.

dp = (0.019*Q^1.9/de^5.02) * Lgth - from Eqn 1

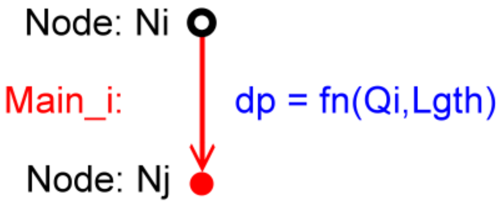


Figure 16: Main line pipe segment 'Main_i'

Determining the air inflow rate via a lateral based on vacuum pressure at the main line junction
For a lateral the air flow rate "q" obtained from a set pressure drop "dp" for a given diameter "de" and length "Lgth" is a function of *(dp,de,Lgth)* and may be calculated from
Eqn 1 re-arranged as:

q = [(dp*de^5.02)/(Lgth*0.019)]^0.526 - Eqn 8 (as Eqn 1 rearranged)

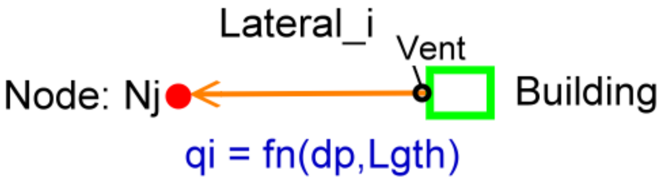


Figure 17: Sideline pipe segment 'Lateral_i'

Entry, exit, and bend losses could be added but are generally low compared the approximate nature of the empirical formulae and the approximations of de.

Summary of the analysis procedure:

1. Set the primary air inlet target air inflow rate (can be any value if recalculating as per step 5).
2. Calculate the vacuum increment (dp) for the first pipe length using Eqn 1.
3. Calculate the lateral air inflow (q) via Eqn 2 using the node vacuum pressure.
4. Repeat while summing the vacuum and lateral inflow increments.

5. Run Excel’s “Goal Seek” function to recalculate all values to match the target extraction air flow rate, or the target extraction vacuum pressure, by changing the primary air inlet air flow rate cell.

This can be repeated for several air extraction rate/vacuum pressure (Q, P) values to generate a Vacuum/Flow system curve for over-plotting onto the odour device fan curve. The intersection point of the system curve and the fan curve defines the fan and system operating point.

Of note is that there is generally an exponential drop off of vacuum pressure and flow rate due to lateral air inflow, especially with smallish diameter main line pipes. Where rapid vacuum drop off is likely it is recommended that odour extraction utilises a gravity pipe length with no laterals and this pipe should be sized so that it never flows more than half full.

15 Air Velocity and Flow Rate Measurement

15.1 Turbulent Air Flow in Pipes

Most flows encountered in engineering practice are turbulent (Reynolds Number (Re) > 4000; See Cl.13), and thus it is important to understand how this affects the velocity profile and the difficulty in measuring the air flow rate. Turbulent flow is a complex mechanism for which the theory of turbulent flow remains largely undeveloped. Therefore, it is standard practice to rely on empirical or semi-empirical correlations developed for various situations.

Turbulent flow is characterized by random and rapid fluctuations of swirling regions of fluid, called eddies, throughout the flow. These fluctuations provide a rapid mechanism for momentum and energy transfer. In comparison, in laminar flow (Re < 2300), momentum and energy are transferred across streamlines by molecular diffusion.

In turbulent flow, the swirling eddies transport mass, momentum, and energy to other regions of flow by advection much more rapidly than molecular diffusion, such as that associated with much higher values of friction, heat transfer, and mass transfer coefficients.

Typical velocity profiles for fully developed laminar and turbulent flows are shown in the figures below.

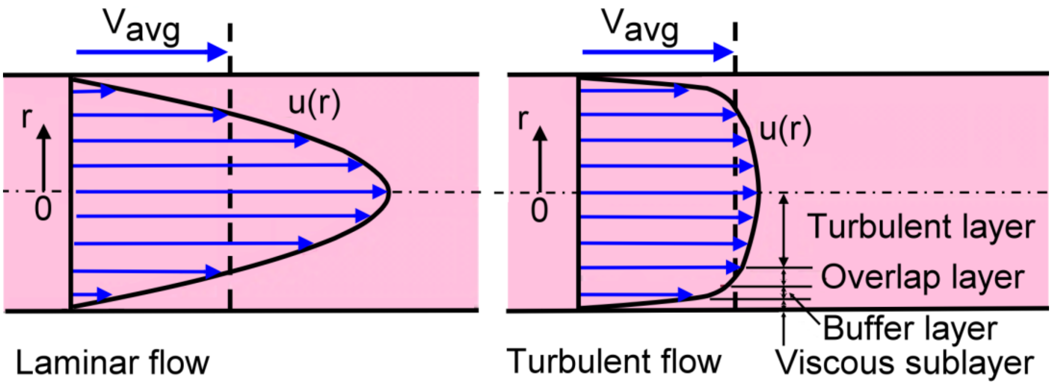


Figure 18: Typical time averaged velocity profiles for fully developed laminar and turbulent flows

In the turbulent flow the simple D-shaped profile is actually the time averaged sequence of fluctuating velocity profiles such as shown below.

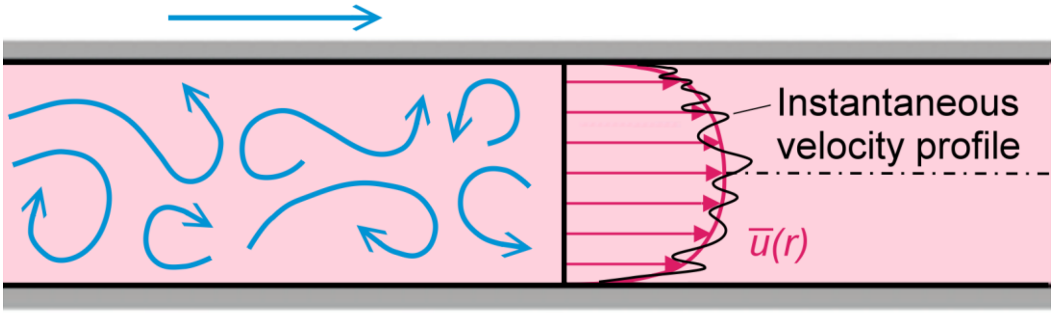


Figure 19: Typical turbulent flow velocity snapshot showing eddy fields and an example instantaneous velocity profile.

Another example of the turbulent flow eddy field in a pipe is shown in Figure 20 below, this time as a cross section. This is a snapshot of rapidly changing vortices in motion in a long straight pipe. Here green is the wall viscous sub-layer, yellow is the buffer layer, orange is the part turbulent transition layer, and red is the fully turbulent flow.

15.2 Velocity Measurement Access Ports

Access port(s) must be provided that allow insertion of a velocity probe as a Pitot tube or hot wire anemometer or spinning vane anemometer. Typically a port should be no less than 25mm clear opening for a small air pipe (100-150mm diameter) and 50mm for larger pipes (>180mm diameter) and must include an easily removed screw cap. An example detail is shown as Figure 9 in Section 7.

The measurement point should have 20 straight pipe diameters upstream, or 50 diameters if there is a double bend or a flow baffle or a fan upstream, or 10 lengths if a flow straightener is included, and 5 straight pipe diameters downstream. The need for these straight lengths is to damp out feature induced spiralling eddies that will amplify point peak velocities and so interfere with flow rate determination.

15.3 Velocity Measurement

Highly accurate flow measurement requires velocity measurements on multiple axes at up to 20 points total. (See Walter, 2022). Provided the required upstream and downstream straight pipe lengths are provided as above then readings on a single axis may be sufficient.

On that one axis it is still necessary to check that the velocities on opposite walls are similar and that the peak velocity is actually on the pipe centreline.

Seal the port opening around the anemometer when undertaking velocity measurements – a cloth or plastic bag is generally sufficient for this purpose.

Three Point Method to obtain Mean Velocity

Air velocity observations at vertical quarter points in air ducts have shown that asymmetry often occurs between the upper and lower quarter point velocities, and sometimes with peak velocity not at the centre.

In a uniform turbulent flow the upper and lower quarter point velocities should be about 96% of the centre velocity with velocity dropping off rapidly from the quarter points to the duct wall.

Ideally velocities would also be measured at the outer 1/8 points but in practice with small ducts it can be difficult to correctly position an anemometer at those locations.

The three point site measurement procedure and the method of calculation is as follow:

1. Measure the depth from the access port top down to the duct invert level.
2. Obtain the duct ID from the design data or measure directly.
3. Calculate the depth from the access port top to the three ¼ points. (See Figure below).
4. Measure the three quarter point velocities.
5. If the velocities at a point are variable then take several readings and average these.
6. Apply weighting factors to the velocities as per the Table 13 example below.
7. Sum the weighted velocities to obtain the duct mean air velocity.
8. Multiply the duct mean air velocity by the duct area to yield the air flow rate.

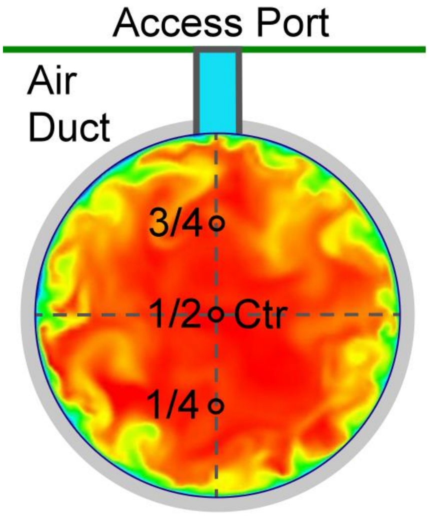


Figure 20: Three point velocity measurement points overlaid on an example typical turbulent flow eddy field

Table 13: Example 3 Point velocity derived flow rate based on actual readings at the Settlers Crescent odour filter

Location on Diameter Line	Velocity (m/s)	Weighting Factor	Velocity x Weighting	DN175 Duct Area (184 ID)	Total Airflow Rate
Upper quarter point	4.8	0.42	2.0		
Centre	5.1	0.06	0.3		
Lower quarter point	4.4	0.42	1.8		
	Sum =	Duct Mean Vel:	**4.1 m/s**	0.0266 m^2	**0.11 m^3/s**

Note that the weightings are derived from the segment areas and the relationship between point velocity and area weighted mean velocity for those segments based on a turbulent flow hyperbolic velocity profile approximation curve. See Walter, 2022 for more detail on this topic including the velocity weighting factor derivation.

Highly Simplified Mean Velocity Determination based on Centre Velocity Only

Where the upstream straight length exceeds 20x diameter and the downstream straight length exceeds 5x diameter and there is not a fan within 50 diameters (unless a flow straightener is included) and velocity is similar near the opposite side walls and the peak velocity is central then, with these conditions confirmed, it is likely that the velocity profile is of a form where the section mean velocity (u_m) will be about 80% of the centre peak velocity (u_c). In this case the total air flow rate (Q_a) for a pipe of cross sectional area (A_p) is then:

$$Q_a = 0.8 * u_c * A_p \qquad \text{- Eqn 9}$$

15.4 Direct Volume Measurement

The air flow rate can also be determined by direct volumetric measurement via the inflation time of a known volume. The most practical container for this is a large polymer collapsible sphere such as low cost beach balls that are available in a whole range of diameters up to 3.6m.

A 1m diameter ball has an internal volume of 550 litres and a 1.2m ball has a volume of 950 litres. At an air flow rate of say 50 L/s a 1m ball will take 11 seconds to inflate and a 1.2m ball 19 seconds.

16 Useful Numbers

Air pressure: 1 mm H_2O = 9.80 Pa at 20°C

Standard atmospheric pressure: 101.3 kPa

Standard atmospheric air density: 1.225 kg/m^3 at 15°C

Hydrogen Sulphide (H_2S) density: 1.45 kg/m^3 at 15°C

H_2S density relative to air: 1.18 x Note: H_2S is heavier than air so can puddle

The **Reynolds Number** (Re) quantifies the relative importance of inertial driving forces in a moving fluid against the viscous drag forces and is a guide to when turbulent flow will occur.
Reynolds Number is the ratio of inertial forces to viscous forces expressed as:

$Re = \rho VD/\mu$

Where:

D = Pipe Dia
V = Air Velocity
ρ = Air Density
μ = Air Dynamic Viscosity

The Reynolds Number laminar/turbulent flow thresholds for flow in a circular pipe are:

Laminar Flow:	$Re < 2300$	Parabolic velocity profile
Transition state if:	$2300 < Re < 4000$	
Turbulent Flow:	$Re > 4000$	Logarithmic/ D shaped profile

Example Reynolds Number calculation:

$\rho = 1.225$ kg/m^3 - Air Density at 15°C

$\mu = 1.81E-5$ Pa.s - Air Dynamic viscosity at 15°C

D = 0.15m; V = 3.0 m/s => Re = 30456 that is > 4000 so flow is turbulent

17 References

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18 Appendices

18.1 Biofilter O&M Checklist

18.2 Activated Carbon O&M Checklist

18.3 Bio-scrubber O&M Checklist

Item #	BIOFILTER O&M CHECKLIST	Frequency					
		monthly	6-monthly	annually	2 years	5 years	ad-hoc
A	**CIVIL / CHEMICAL**						
	Operational Checks						
1	Have any odour complaints been received?	X					
2	Are odours apparent on site?	X					
3	Assess media condition at multiple depths	X					
4	Check that irrigation is even and consistent; check bed moisture	X					
5	Check media level and depth	X					
6	Check for any bed short-circuiting and for evenness of air flow through the bed	X					
7	Check that the leachate drain flows clearly, including airtrap	X					
8	Check any associate splash structure for deposition or blockages (discharge MH)	X					
9	Check structure integrity	X					
10	Condition assessment and asset verification			X			
11	**Maintenance Tasks**						
12	Troubleshoot as required from operational checks	X					
13	Weed the media bed	X					
14	Clean and maintain the surrounds	X					
15	Media rework and top-up (including sampling of media across bed)				X or earlier if required		
16	Media replacement, including smoke test once complete						typ. 5 - 8 yrs but for small, high use beds, could be earlier
17	Check and replace (if needed) all pipework, seals, valves and fittings						with media replacement
18	Inspect base of media bed						with media replacement
19	Inspect air isolation valve on air duct including exercising the valve			X			
	Monitor, record and report						
20	Differential pressure across the bed. Note: Max. allowable differential pressure is 700 Pa.	X					
21	Report any and all issues	X					
22	Report media rework and top-up date / extent						X
23	Report media replacement date						X
B	**MECHANICAL**						
	Operational Checks						
1	Inspect fan components / operation	X					
2	Check fan speed at agreed value	X					
3	Condition assessment and asset verification			X			
	Maintenance Tasks						
4	Troubleshoot as required from operational checks	X					
	Monitor, record and report						
5	Airflow rate (independent check)			X			
6	Extraction fan speed, where instrument fitted	X					
7	Run hour meter	X					
8	Report any and all issues	X					

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Item #	BIOFILTER O&M CHECKLIST	Frequency					
		monthly	6-monthly	annually	2 years	5 years	ad-hoc
C	**ELECTRICAL / CONTROLS**						
	Operational Checks						
1	Annual electrical inspection			X			
2	Condition assessment and asset verification			X			
	Maintenance Tasks						
3	Troubleshoot as required from operational checks			X			
	Monitor, record and report						
4	Power reading	X					
5	Report any and all issues	X					

Item #	ACTIVATED CARBON O&M CHECKLIST	Frequency					
		monthly	6-monthly	annually	2 years	5 years	ad-hoc
A	**CIVIL / CHEMICAL**						
	Operational Checks						
1	Have any odour complaints been received?	X					
2	Are odours apparent on site?	X					
3	Check structure integrity	X					
4	Check locks are in place and functional	X					
5	Inspect and clean surrounds	X					
6	Condition assessment and asset verification			X			
	Maintenance Tasks						
6	Troubleshoot as required from operational checks incl clean, repair, replace	X					
7	Troubleshoot if odour complaint						X
8	Replace cartridge / carbon						plan when saturation 90% - replace at 100%
9	Inspect air isolation valve on air duct including exercising the valve (where relevant)			X			
	Monitor, record and report						
10	Remove dipstick and measure length - calculate carbon bed saturation rate. Where no dipstick, record and report any other saturation indicators.	X					
11	Report any and all issues	X					
12	Report when cartridge / carbon replaced						X
B	**MECHANICAL**						
	Operational Checks						
1	Inspect fan components / operation (where fitted)	X					
2	Check fan speed at agreed value (where fitted)	X					
3	Check if heater is operational (where fitted)	X					
4	Condition assessment and asset verification			X			
	Maintenance Tasks						
5	Troubleshoot if no airflow rate						X
6	Troubleshoot if noise complaint						X
7	Troubleshoot as required from operational checks	X					
	Monitor, record and report						
8	Airflow rate (independent check) (where fitted)			X			
9	Extraction fan speed (where fitted)	X					
10	Run hour meter (s) (where fitted)	X					
11	Report any and all issues	X					
C	**ELECTRICAL / CONTROLS**						
	Operational Checks (where relevant)						
1	Annual electrical inspection			X			
2	Condition assessment and asset verification			X			
	Maintenance Tasks (where relevant)						

Item #	**ACTIVATED CARBON O&M CHECKLIST**	**Frequency**					
		monthly	**6-monthly**	**annually**	**2 years**	**5 years**	**ad-hoc**
3	Troubleshoot as required from operational checks	X					
	Monitor, record and report (where relevant)						
4	Power reading	X					
5	Report any and all issues	X					

Item #	BIOSCRUBBER O&M CHECKLIST	Frequency					
		monthly	6-monthly	annually	2 years	5 years	ad-hoc
A	**CIVIL / CHEMICAL**						
	Operational Checks						
1	Have any odour complaints been received?	X					
2	Are odours apparent on site?	X					
3	Check water flowrate and timing ensuring adequate coverage of bed	X					
4	Top up nutrient dosing tank	X					
5	Test if dechlorinator working (chemical kit required)	X					
6	Check setting of timers on dosing pump / solenoid valve	X					
7	Check all hatches and covers in place and securely bolted	X					
8	Check structure integrity	X					
9	Check locks are in place and functional	X					
10	Inspect and clean surrounds	X					
11	Condition assessment and asset verification			X			
	Maintenance Tasks						
12	Troubleshoot as required from operational checks incl clean, repair, replace	X					
13	Troubleshoot if odour complaint						X
14	Replace carbon						plan when saturation is at 90% - replace at 100%
15	Replace dechlorinator cartridge				X or earlier if required		
16	Inspect air isolation valve on air duct including exercising the valve			X			
	Monitor, record and report						
17	Remove dipstick and measure length - calculate carbon bed saturation rate	X					
18	Record H2S incoming / between stages / outgoing, where monitors fitted or measure and record where monitoring points only provided	X					
19	Report any and all issues	X					
20	Report when carbon replaced						X
21	Report when dechlorinator catridge replaced						X
B	**MECHANICAL**						
	Operational Checks						
1	Inspect fan components / operation	X					
2	Check fan speed at agreed value	X					
3	Check if heater is operational	X					
4	Condition assessment and asset verification			X			
	Maintenance Tasks						
5	Troubleshoot if no airflow rate						X
6	Troubleshoot if noise complaint						X
7	Troubleshoot as required from operational checks	X					
	Monitor, record and report						
8	Airflow rate (independent check)			X			
9	Extraction fan speed	X					
10	Run hour meter (s)	X					
11	Report any and all issues	X					

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Item #	BIOSCRUBBER O&M CHECKLIST	Frequency					
		monthly	6-monthly	annually	2 years	5 years	ad-hoc
C	ELECTRICAL / CONTROLS						
	Operational Checks						
1	Annual electrical inspection			X			
2	Condition assessment and asset verification			X			
	Maintenance Tasks						
3	Troubleshoot as required from operational checks	X					
	Monitor, record and report						
4	Power reading	X					
5	Report any and all issues	X					