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Biofilters for controlling animal rendering odour—a pilot-scale study

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Abstract: The performance of biofiltration to remove odours from animal rendering plant's gaseous emissions was investigated using pilot-scale biofilters containing different media (sand, sawdust, bark, bark/soil mixture). Biofilter influent and effluent gases were characterised using a gas chromatograph-mass spectrometer (GC-MS) and a GC fitted with an odour "sniffing" port. Overall odour-removal performance of the biofilters was determined using a forced-choice dynamic-dilution olfactometer.

The biofilter influent gases contained about 300 organic compounds, of which approximately 40 were odorous. The odorous compounds included alkanes, alkenes, ketones, hydrocarbons, alcohols, alkyl halides, fatty acids, amines, aromatics, aldehydes and epoxides. The biofilters reduced the concentrations of the odorous compounds, often to levels that were undetectable by the GC. Some of the odorous compounds in the biofilter effluent gas came from the biofilter medium or were the result of biological or chemical transformations within the biofilter.

Biofilter odour removal efficiencies of between 75% and 99% were measured at influent odour concentrations of between 490,000 and 1,100,000 odour units m^{-3}, and various air loading rates (0.074-0.057 m^{-3} gas m^{-3} medium min^{-1}) and medium moisture contents. Biofilters with new media, low air loading rates, or high medium moisture contents generally gave the best odour removal. Different biofilter media gave similar odour reductions at the gas loading rates examined.

Keywords: Odour, biofilters, animal rendering, olfactometry, GC-MS

INTRODUCTION

The heating of animal tissues during rendering liberates a variety of odorous organic and inorganic compounds (refs.1,2,3). The odours can be objectionable and must therefore be controlled. Conventional techniques for deodorising the hot rendering gaseous emissions include condensation, incineration and chemical oxidation (refs.1,4,5,6).

Over the last decade, biofilters ("soil filters") have become a popular odour-control option, and approximately 40% of New Zealand animal rendering plants now use biofilters which are usually effective, but sometimes odour removal performance is unreliable (ref.7). As gases pass through a biofilter, odorous compounds are removed by processes thought to include absorption/adsorption and bio-oxidation (ref.8). The odorous gases and particulates adsorb onto the surface of the biofilter medium and/or are absorbed into the moisture film on the biofilter particles. Given a sufficient rate of biological activity in the filter, the sorbed compounds are then oxidised by microorganisms. End products from the complete bio-oxidation of the air contaminants are CO_2, water, mineral salts, and microbial biomass.

Biofilters have become a popular means of controlling odours from a variety of sources (refs.8,9,10,11), but few papers discuss their application to treating rendering emissions (ref.12 & 13), and there is a lack of reliable information on biofilter performance and design criteria.

Towards the goal of developing design criteria for rendering gas biofilters, this study investigated the nature and variability of rendering process gaseous emissions, and measured the odour-removal performance of a variety of biofilter media for these emissions under various operating conditions. The rendering gas characteristics and biofilter performance were assessed using a gas chromatograph-mass spectrometer, a gas chromatograph with an odour sniffing port, and an olfactometer.

MATERIALS AND METHODS

Pilot-scale biofilters

Pilot-scale biofilters were established at a rendering plant, at which animal offal was rendered in a MIRINZ Low Temperature Rendering system (MLTR), and the meat and bone meal was dried in two direct-fired dryers. The experimental biofilters treated the exhaust gases from the dryers, after dust removal in a cyclone separator, and cooling through condensers and a heat recovery system. The cooled gases, as well as being odorous, contained significant smoke from the scorching of product. The temperature of the biofilter influent gas was about 30-35°C.

Each biofilter was constructed in an upright cylindrical plastic drum, with an internal diameter (i d) of 625 mm and a height of 910 mm (Fig. 1). The biofilters were located outdoors, and were insulated with a 25 mm thick layer of closed-cell plastic foam to minimize temperature variations within the biofilters. The top of each biofilter was open except during sampling. The influent gas was introduced into the base of the biofilter medium, through a perforated stainless steel plate covered by a 30 mm layer of 6-8 mm gravel chips (Fig. 1). A valve near the base of the biofilter drum allowed drainage liquid to be collected.

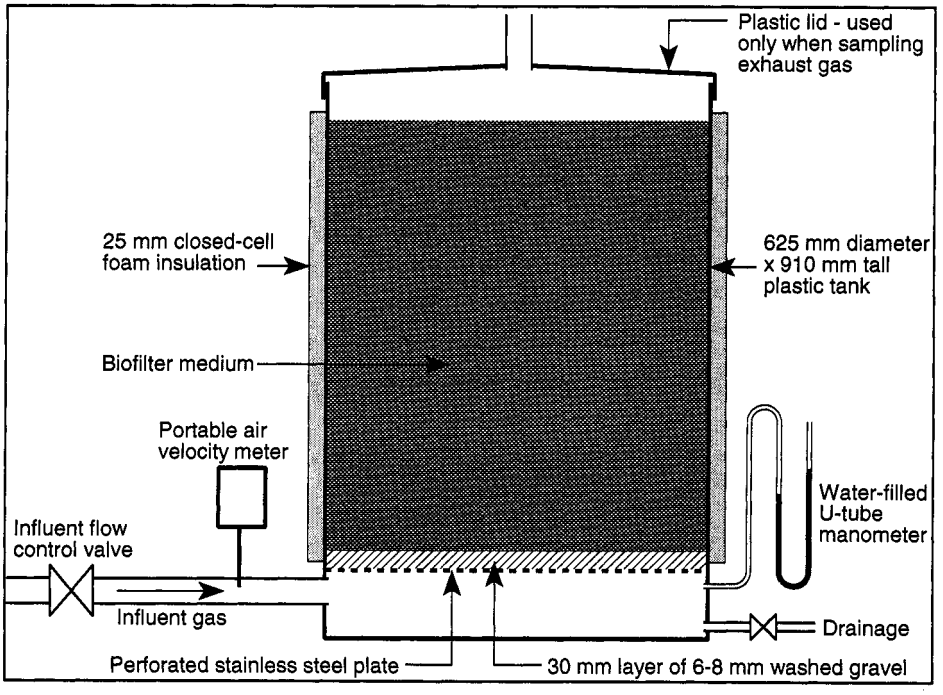

Fig.1. Schematic of a pilot-scale biofilter

Different natural media were tested in the biofilters, including unwashed sand (pit sand), washed sand, sawdust, different grades of crushed pine bark, and a mixture of soil and coarsely crushed pine bark. The media were placed loosely into the biofilter drums to a depth of 700-770 mm.

Operation of biofilters

The volumetric gas loading on each biofilter was determined by measuring the gas flow velocity in the inlet pipe, using a portable air velocity meter (Model 443M, Kurz Instruments Inc.), and controlled by manually adjusting a ball valve in the inlet pipe. The gas loading was continuous, except during regular one- or two-day plant shut-downs on weekends. The specific gas loading rate on each biofilter was usually about 0.29 m^3 gas

m^{-3} medium min^{-1}, but was sometimes temporarily increased or decreased to determine the effect of loading rate on biofilter performance.

The pressure drop across the biofilter medium was measured using a water-filled U-tube manometer. The moisture content of the media was determined non-destructively, by relating the total weight of each biofilter to the weight at field capacity, after draining the leachate. The temperature of the influent gas was monitored using thermocouples linked to a data logging system. Routine monitoring also involved recording rainfall and leachate volumes.

Performance studies and biofilter medium characteristics

Studies were conducted to assess biofilter odour reduction efficiency on two occasions. On the first occasion (study 1), five biofilters were evaluated. These biofilters contained: unwashed pit sand, washed and screened sand (< 2 mm), sawdust, finely crushed bark (< 10 mm), or a mixture of soil (30% v/v) and coarsely crushed wood bark (< 20 mm) (70% v/v), placed in the drums to a depth of 700 mm. The biofilters had operated for two weeks before biofiltration performance was measured. In this and the second study, the sawdust and bark were from pine trees (*Pinus radiata*).

On the second occasion (study 2) the evaluated biofilters consisted of finely crushed bark, coarsely crushed bark, or a mixture of soil (30%) and the coarsely crushed bark (70%), placed in the drums to to a depth of 770 mm. The particle sizes of the media are given in Table 1. These media were similar to those used in study 1, but had been changed between the two studies. The biofilters in study 2 had operated for three months before undertaking the performance measurements.

TABLE 1. Particle size distribution of the Biofilter Media used in Study 2. Values are % dry weight.

Particle size	Fine bark	Coarse bark	Soil & coarse bark
>5.6 mm	16.8	95.2	76.0
2.8-5.6 mm	32.8	2.8	8.2
2.0-2.8 mm	10.6	0.4	10.4

Gas sampling

Gas samples for chemical and sensory analyses were collected into Mylar bags, which were each mounted in a rigid plastic drum with a sealable lid. Each bag had a stainless steel valve that protruded through the lid and was extended to the sampling point using a 6 mm id PTFE (Teflon) tube. A stainless steel fitting with Teflon ferrules connected the tubing to the valve.

The dilution capacity of the olfactometer was limited to 10,000 odour units (OU) m^{-3}; therefore pre-dilution of the odorous gas sample in the study was generally necessary to give a sample odour concentration below 10,000 OU m^{-3} (for a definition of odour units, see below). Often the gas samples were pre-diluted to below 5,000 OU m^{-3}, to speed the olfactometric analysis and to minimize the risk of air condensing in the sample bags. Pre-dilution involved placing a known amount of odour-free N_2 gas into the Mylar bags, before adding a measured sample volume. A new sampling bag was used for each sample.

An additional pre-dilution step was used for the biofilter influent gas samples. The influent gas was sampled through a small hole in the biofilter inlet pipe using a venturi-containing device, which simultaneously sampled and diluted the rendering air with odour-free N_2 at pre-determined ratios. The device had been calibrated before use. Between samples, the sampler was decontaminated by flushing with N_2 gas. A lid with a 50 mm diameter vent (Fig. 1) was placed over each biofilter at least five minutes before collection of a biofilter effluent gas sample. The gas sample was drawn from under the sampling lid, directly into a Mylar bag, by evacuating the air between the bag and the sealed plastic drum, using an air pump. All samples were stored in the dark at room temperature, and analysed within 24 hours of collection.

Concentrating samples

To detect many of the trace compounds in the biofilter influent and effluent gas samples, it was necessary to concentrate the samples. The concentration technique involved passing a known volume of sample (usually

800 ml) through a porous polymer trap (at a rate of about 100 ml min^{-1}) that adsorbed the organic compounds in the sample. The polymer trap consisted of a glass tube (175 mm long x 6 mm I d) containing about 200 mg Tenax-GC. (In initial trials, two traps in series were used to determine trapping efficiency. No compounds were detected in the second trap, so the use of one trap became the usual procedure.)

Gas chromatography

The volatile compounds adsorbed on the Tenax-GC polymer were thermally desorbed into the gas chromatographs. The polymer trap was inserted into a heating jacket, and was connected to the GC injection port with a sampling needle. Desorption was accomplished by rapidly raising the trap temperature to 250°C (in less than 2 minutes), and then, while maintaining this temperature, purging the adsorbent with helium for 10 minutes. The injection port was held at 260°C to avoid condensation of high-boiling-point compounds. Following thermal desorption, the volatiles were cryofocussed at the head of the column by cooling the oven using liquid CO_2, before starting the temperature programme.

The gas chromatograph-mass spectrometer (GC-MS) used was a Fisons Instrument (MD 800), with a bonded fused silica capillary GC column (DB 5ms, 30 m long and 0.25 mm i d, 1.0 μm film). The temperature of the column oven was raised from -10°C to 40°C over one minute, and held at 40°C for 5 minutes. The temperature was then raised to 260°C at 5°C min^{-1}. The temperature was held at 260°C for 2 minutes, and then raised to finally 300°C at 20°C min^{-1}. The MS was operated with an electron ionisation potential of 70 eV; a source temperature of 200°C and an interface temperature of 300°C. MassLab software (ref.14) was used to control the GC-MS operation parameters and to record and analyse results.

An "odour sniffing" port, attached to another gas chromatograph (Hewlett 5890 series II), was used to determine the odour characteristics of compounds as they eluted from the GC column. This chromatograph was also equipped with a flame-ionisation detector (FID). The type of column and temperature/time programme were generally the same as used with the GC-MS, except the column i d was 0.53 mm. In this system, the column-separated gases were split (1:1) between the odour port and the FID. Humidified air was combined with the hot GC effluent, before sniffing by an experienced odour sniffer.

As odorous compounds (and possibly groups of compounds) were eluted from the column, the GC retention time at which an elute occurred was recorded, as well as the odour characters. Software (Maxima 820) was used in conjunction with the sniffing port to help in identifying and logging the smell. Retention time values were converted to Kovats' retention indices using alkane series standards from the chromatograms produced by both the GC-MS and the GC-odour port. GC-MS analysis was used to identify the compound with the same retention indices as the odours detected through the odour port. Each compound, or the group to which it belongs, was identified from its mass spectrum with the aid of the MassLab software incorporating an NIST mass spectral data base of 62,000 compounds, and on the basis of knowledge of fundamental fragmentations.

Olfactometry

A forced-choice dynamic-dilution olfactometer with the dilution-to-threshold approach was used to determine the biofilter odour-removal efficiency. The olfactometer was designed and operated in accordance with the 1990 Dutch Pre-Standard for Sensory Odour Measurements Using an Olfactometer (ref.15). In summary, the odour measurements involved an eight-member panel, with each panellist having three ports to choose from. One randomly selected port delivered the sample at a certain dilution, and the other ports contained deodorized air. During each analysis, the panellists were presented with an increasing odour concentration of the sampled air. The number of dilutions to threshold was calculated for each individual panellist by taking the geometric mean of the lowest dilution factor for which their choice of port was wrong (i.e. the port chosen did not have the diluted odour), and the dilution factor of the next presentation. The resulting number estimated the number of dilutions to reach the threshold for the individual, when at their mean sensitivity level. The odour concentration in the air was determined as the number of odour-free air dilutions at which 50% of the panel could just detect an odour, and was expressed as odour units per cubic metre (OU m^{-3}). The eight calibrated panellists had detection thresholds for n-butanol within the range of 20-80 ppb. The mean panel n-butanol threshold was 27 ppb for study 1, and 41 ppb for study 2. The repeatability of results was

tested by analysing 18 samples in duplicate. The mean range of duplicate results was 30.9% of the duplicate mean.

RESULTS AND DISCUSSION

TABLE 2. Characteristics of the influent and effluent gas for the biofilter containing a mixture of soil and bark during study 1.

Compound no.	Odour presence*	Odour character	Possible compound group as determined by GC-MS
1	I,E	hot oven	cyclic ether
2	I,E	musky stink	unsaturated hydrocarbon
3	I,E	hot buttery	aromatic
4	E	solvent	unknown
5	I	musky	aldehyde
6	I	solvent	epoxide
7	I	solvent	unknown
8	I	buttery	epoxide
9	I	solvent	alkane
10	I,E	?	alkyl halide
11	I	solvent	heterocyclic compound
12	I	solvent	unknown
13	I	burnt	amine
14	I,E	?	hydrocarbon
15	I	musky	alkene
16	I	musky	alkyl halide
17	I,E	burnt	aromatic
18	I,E	?	ketone
19	I	sweet	heterocyclic compound
20	I,E	solvent	alkane
21	I	hot buttered scone	alkane
22	I,E	dentist drilling	alkyne
23	I,E	burnt toast	aldehyde
24	I	?	aromatic
25	I,E	mushroom	alkane
26	E	earthy	unknown
27	I,E	?	alkane
28	I	damp	alicyclic hydrocarbon
29	I	damp	aromatic
30	I,E	?	alkyl halide
31	E	sweetish	unknown
32	I	mushroom	alcohol
33	I	burning bones	alkane
34	I	musky	alkane
35	I,E	stale bread	ketone
36	I	?	alcohol
37	E	dusty	unknown
38	E	mushroom	unknown
39	E	earthy	alicyclic hydrocarbon
40	I	?	alkene
41	I	nutty/cooked	alkane
42	I	hot hairdrier	ketone
43	I	burnt meat	fatty acid
44	I	burnt meat	aromatic
45	I	hot iron	alkane
46	I	?	alkane
47	I	singed hair	fatty acid
48	I	?	alkane
49	I	raw potato	unknown

* I - present in influent; E - present in effluent.

Odour components and their removal

Figure 2 shows an example of GC-MS chromatograms of the influent and effluent gas sampled at about the same time for the soil-bark biofilter during Study 1. Figure 2 also gives the corresponding odour appearance in these samples, as measured by the GC-odour port technique.

The GC-MS chromatograms revealed about 300 organic compounds (Fig.2). For all compounds detected, the relative concentration in the effluent gas, measured in total ion counts, was less than 1% of that in the influent, indicating greater than 99% removal. Similar reductions were found for the other biofilter media types (data not shown).

For this sampling, 43 of the biofilter influent compounds and 20 of the effluent compounds were odorous (Fig.2), as measured by the GC-odour port technique. (We have assumed that each odour component measured using the odour port is a single compound.) The odorous compound groups included alkanes, alkenes, ketones, hydrocarbons, epoxides, aldehydes, aromatics, alcohols, amines, alkyl halides and fatty acids, and had a variety of odour characters (Table 2).

Fourteen of the 43 odorous components in the biofilter influent gas were detected in the effluent (Fig.2). The intensities of these 14 compounds, as estimated by the sniffer, and taking into account sample dilution factors, were much lower than in the influent gas (data not shown). Six of the odorous compounds detected in the biofilter effluent gas were not in the influent. These compounds may have come from the biofilter medium or from the breakdown or conversion of organic compounds present in the influent gases in the biofilter medium. Of four biofilter influent samples collected over four days

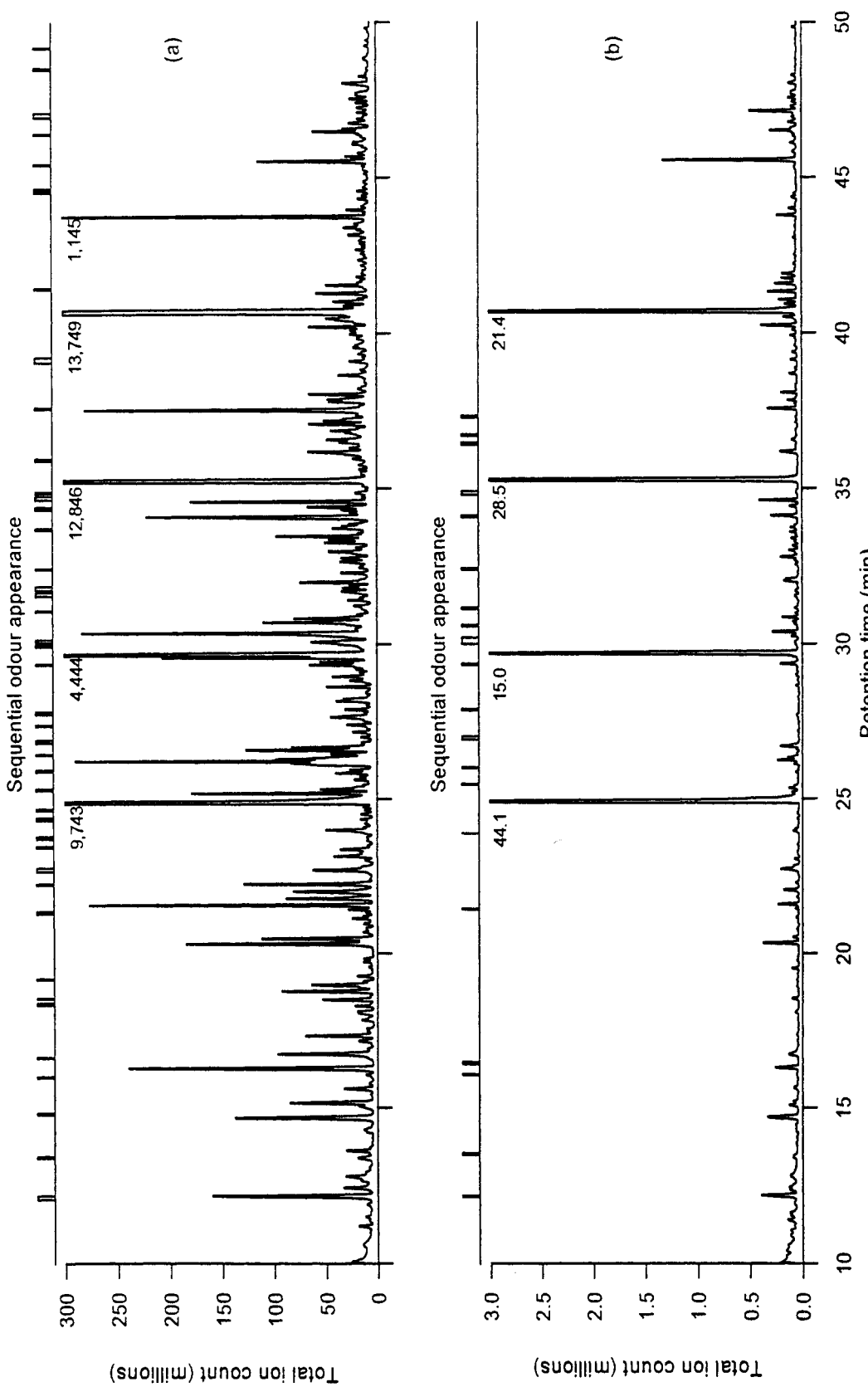

Fig. 2. GC-MS chromatograms of the soil/bark biofilter influent (a) and effluent (b) gases sampled at about the same time, and the corresponding odour appearance. The total ion count has been adjusted from the obtained GC-MS chromatogram according to the sample dilution factor. The retention time scale for odour appearance has been adjusted to be the same as that for GC-MS, using Kovats' indices. Several peaks exceeding the y-axis scale have been truncated, but the heights of these truncated peaks are given.

3). Medium moisture content is well established as an important factor affecting the odour removal efficiency and pressure drop of biofilters (refs. 16 & 17).

TABLE 4. Performance of biofilters that had been operating for 3 months (study 2). The gas loading rate was 0.29 $m^3 m^{-3} min^{-1}$.

Biofilter medium	Medium moisture content (% field capacity)	Pressure drop (mm water)	Effluent odour concentration (OU m^{-3})	Reduction in odour concentration (%)
Sampling Run 1 (Influent odour concentration 490,000 OU m^{-3})				
Fine bark	92	11	62,000	87.3
Coarse bark	65	3	124,000	74.7
Soil and wood bark	87	8	66,000	86.5
Sampling Run 2 (Influent odour concentration 1,100,000 OU m^{-3})*				
Fine bark	100	14	130,000	88.2
Coarse bark	100	5	130,000	88.2
Soil and bark	100	8	100,000	90.9

* Sampling Run 2 occurred 3 days after Run 1, and the day after 43 mm of rainfall.

In Study 2, a further experiment was undertaken in which the fine bark and soil/bark biofilters were evaluated at gas loading rates ranging between 0.074 and 0.57 m^3 gas m^{-3} medium min^{-1}. (The biofilters were operated for at least 4 hours at a given loading rate before sampling of the influent and effluent gases.) As the loading

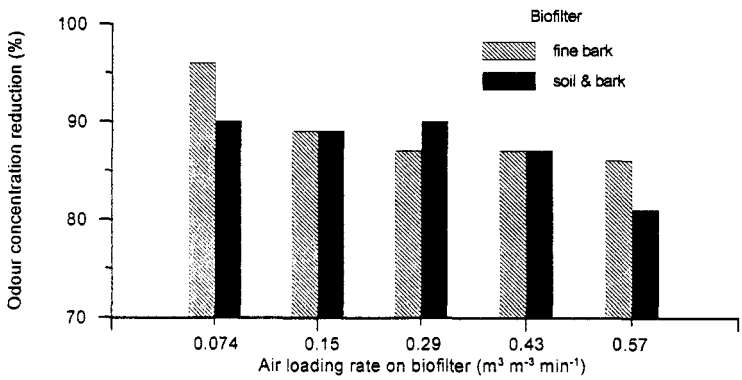

Fig. 3. Effect of air loading rate on odour concentration reduction through the fine-bark and soil/bark biofilters measured during study 2. The moisture content of the biofilter media was at field capacity, and the influent odour concentration varied between 620,000 and 1,100,000 OU m^{-3}.

rate was increased, the odour removal performance tended to decrease (Fig. 3), although a large increase in loading rate produced only a small decrease in performance.

The air-filled pore space in the media was not determined, but assuming this was 50%, the mean gas residence time in the experimental biofilters ranged from 53 seconds (0.57 $m^3 m^{-3} min^{-1}$) to 6.7 minutes (0.074 $m^3 m^{-3} min^{-1}$). Residence times of 30-120 seconds are commonly used for the design of biofilters treating odours from compost facilities and wastewater treatment plants (refs. 18,19,20). Most biofilters at New Zealand rendering plants operate with gas residence times of 1-7 minutes (ref.7).

Medium type did not have a significant effect on the odour-removal performance of the biofilters. The good performance of the sand biofilters in Study 1 suggested that an organic medium was not necessary, at least during the early stages of biofilter operation. An ideal medium would maintain a low resistance to airflow over several years of biofilter operation, while having a high surface area available for adsorption/absorption of gaseous compounds and for microbial attachment. The medium must also be available at low cost, as large quantities of media are usually required for full-scale biofilters. We are undertaking further studies to identify the best biofilter medium for treating rendering gas emissions. This work involves better identifying the

relative importance of physical, chemical and biological mechanisms operating to remove odours in biofilters. Long-term changes in the porosity of different media are also being evaluated.

CONCLUSIONS

The animal rendering plant gas contained about 300 organic compounds, of which approximately 40 were odorous. The odour was attributed to a variety of organic compounds including alkanes, alkenes, ketones, hydrocarbons, alcohols, alkyl halides, amines, aromatics, aldehydes, epoxides and fatty acids. The biofilter removed these odorous compounds or significantly reduced their concentrations. Some odorous compounds in the biofilter effluent gas may have come from the biofilter medium or from the breakdown or conversion of organic compounds present in the influent gases while resident in the biofilter medium.

Influent gas odour concentrations of between 490,000 and 1,100,000 OU m^{-3} were reduced by 75-99% by the experimental biofilters. Biofilters with new media, lower air loading rates, or higher medium moisture contents generally performed better. At the air loading rates examined, the different media tested had no obvious consistent effect on the biofilter odour-removal performance.

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