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PILOT-SCALE TRIALS OF BIOFILTERS USING ZEOLITE AND COIR AS FILTER MEDIA TREATING ODOUR COMPOUNDS FROM A COMPOSTING FACILITY

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ABSTRACT

This study investigates odour removal of pilot-scale biofilters treating volatile organic compounds (VOCs) produced during composting of organic fraction of municipal solid wastes (OFMSW). Four biofilters, containing non-biodegradable zeolite, biodegradable coir fibre, and the mixture of both materials, with and without inoculum, were set up onsite to treat the exhaust gases from a local composting facility. Odour-removal efficiencies of the biofilters were monitored by sensory concentration measurement using olfactometry and analytical measurement using gas chromatography-mass spectrometry (GC-MS) on three occasions, at start-up, 3 months and 9 months of operation.

At feeding rate of 1 L/L/min and feed concentration of 9,000-10,000 OU, odour removal efficiencies of the biofilters were over 90% right from start up through to 9-month period of monitoring. Inoculation of biofilter was found to be beneficial but not essential. Based on detailed analysis of odour compounds using GC-MS, zeolite biofilter was effective in adsorbing polar compounds (such as alcohol and volatile acids) while coir biofilter was found to be particularly effective in capturing non-polar VOCs, such as monoterpenes (the main component in the feed stream). The combination of coir and zeolite complemented one another providing very effective removal of both polar and non-polar volatile compounds.

Keywords: Odour control, biofilter, composting facility, zeolite, coir

INTRODUCTION

Composting facilities of OFMSW are well known sources of odourous VOCs due to the OFMSW itself and from microbial decomposition of the waste (Müller et al. 2004; Pagans et al. 2006). To minimise odour emission to surrounding communities, most facilities are fully enclosed with ventilated odourous air stream being treated prior to discharge (Müller et al. 2004a; Müller et al. 2004b1). Various treatment methods can be used, including physical, chemical and biological systems (Schlegelmilch et al. 2004). More recently biological off-gas treatment is gaining popularity. This is due to the low investment and operational costs involved for the elimination efficiencies obtained (Groenestijn & Hesselink 1993). In addition, it is also considered to be more environment-friendly compared to conventional physico-chemical techniques of air pollution control technologies. The most popular configuration used to treat odour compounds from composting facilities is biofilter.

Different materials (biodegradable and non-biodegradable) may be used. Currently, wood chips, compost, soil and peat are the most frequently used filter media (Mudliar et al. 2010). Characteristics including benefit and drawback of different filter media have been reviewed elsewhere (Govind &

Narayan 2008). In this study, we investigate the use of non-biodegradable zeolite and bioactive coir as biofilter materials in removing complex odour and VOCs from a composting facility.

METHODS

Biofilter set up (Figure 1)

To compare odour removal efficiency of coir and zeolite, two 120L working-volume pilot-scale biofilters were set up onsite at Canning Vale Waste Composting Facility, Western Australia. Filter media used were coir (Biofilter 1) or 2.4-4.5 mm zeolite (Biofilter 2). Two additional 45L working-volume biofilters were set up to investigate the efficiency of combined coir and zeolite (Biofilter 3) and the benefit of inoculum during start up (Biofilter 4).

Figure 1: Pilot-scale biofilters set up

Feed for the four biofilters was a side stream redirected from the main airflow from the composting building into the existing biofilter (after humidifier). This side stream then passed through a manifold separating the air stream into 4 sub-streams feeding into the four pilot-scale biofilters. To ensure that all 4 pilot-scale biofilters were fed at the same rate, flow meters were installed for individual sub-streams and adjusted to feed the biofilters at a rate of 1 L/L/minute. To maintain moisture content within the biofilter, leachate circulations were set at 15 min/day (300 L/hour). Operational conditions of the pilot-scale biofilters are summarized in Table 1.

Table 1: Summary of the pilot-scale biofilters

	Filter media	Inoculum	Reactor volume
Biofilter 1	100% Coir	No inoculum	120 L
Biofilter 2	100% 2.4-4.5 mm zeolite	No inoculum	120 L
Biofilter 3	80% Coir + 20% 1-2.4 mm zeolite	With inoculum*	45 L
Biofilter 4	100% 2.4-4.5 mm zeolite	With inoculum*	45 L

*Inoculum was obtained from the existing biofilter by mixing 8 L of old filter media (at 0.5 depth) with 30 L tap water, and then incubating at room temperature for 24 hrs. Supernatant of the mixture was filtered through muslin cloth to remove large particles. Three litres of the supernatant was sprayed on the surface of filter media of Biofilter 3 and Biofilter 4. Leachate circulating pumps were then used to circulate the inoculum through the filter media for 15 minutes.

Sampling and analysis

Odour removal performance measurements of the biofilters were undertaken on three occasions as follows:

Phase 1: Start-up period where the majority of odour removal was believed to be a result of adsorption onto filter media. The samples were taken 12 days after the biofilters had been commissioned.

Phase 2: Short-term operation where (1) adsorption capacity of filter media would be exhausted; and (2) sufficient time for microbial community to establish in the biofilter. Odour removal at this stage should be a result of combined adsorption and biodegradation. The samples were taken 3 months after the biofilters had been commissioned.

Phase 3: Long-term operation to determine the sustainability of the biofilters. The samples were taken 9 months after the biofilters had been commissioned.

Two methods of evaluation were employed; 1) sensory concentration measurement using olfactometry to determine the change of odour strength; and 2) analytical measurement using Gas chromatography-mass spectrometry (GC-MS) to determine the removal of specific volatile compounds in the air stream. At each sampling event 2 air samples were taken from the inlet (feed) and outlets from each pilot-scale biofilters. The first sample was taken using a "lung" technique with 25 L Tedlar bag, which was then sent to The Odour Unit (WA) Pty Ltd for sensory concentration measurements. The second sample was taken using Silco air sampling canisters, and then sent to the Chemistry Centre of Western Australia for identification and quantification of volatile organic compounds (VOCs).

RESULTS AND DISCUSSION

Results of odour sensory concentrations (olfactometry) of inflow and outflow of the four pilot-scale biofilters (Table 2) clearly show significantly high odour removal efficiency of the biofilters over the nine-months of operation. Characteristics of odour were also changed by the biofilters from offensive acid/garbage smell to more acceptable earthy smell (results not shown).

Table 2: Results of odour concentration (ou) of inflow and outflow from pilot-scale biofilters using olfactometric measurement

Sample	1st sampling		2nd sampling		3rd sampling	
	ou	% Odour removal	ou	% Odour removal	ou	% Odour removal
Inflow	10,090		9,363		9,740	
Biofilter 1	197	98	23	99	235	98
Biofilter 2	239	98	90	99	1,020	90
Biofilter 3	69	99	90	99	279	97
Biofilter 4	256	98	85	99	*	*

*Biofilter 4 was prematurely terminated due to technical problem

Phase 1: Start up period

Based on olfactometry, above 98% odour removal was achieved (Table 2) during the start up. This is confirmed by results from detailed analysis using GC-MS based on US EPA TO-14A method (results not shown). It is clear that both coir and zeolite were effective to varying degrees in capturing organic compounds listed in US EPA TO-14A method. It was however found that the main compound in the gas streams, indicated as a major peak (at 26 min.) in GC chromatograms shown in Figure 2, could not be identified due to lack of standard (not being part of US EPA TO-14A method). Based on the mass spectrometry, it was identified as monoterpenes (most likely limonene). By comparing chromatogram of input and output gas from the four biofilters, it is clear that pilot-scale biofilters were able to significantly remove these compounds from the input gas. Since the samples were taken only 12 days after the biofilters were set up, the time was too short to allow microbial communities to fully establish (Iranpour *et al.,* 2005); therefore physical adsorption/chemical reactions between organic compounds and coir/zeolite were believed to play the major role over microbial degradation. The fact that significantly higher reductions of monoterpenes were obtained in Biofilter 1 & 3 than that of Biofilter 2 & 4 indicates that coir is more effective in adsorbing non-polar compounds from the air stream compared to zeolite.

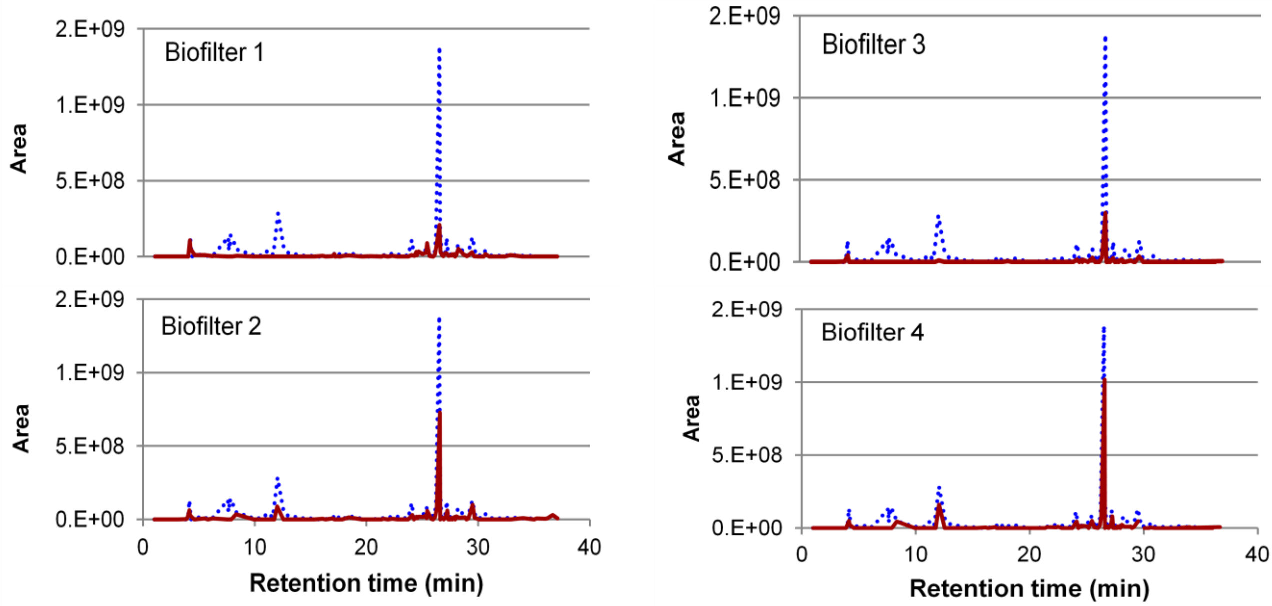

Figure 2: GC chromatogram of outflow from the biofilters odour (red solid line) compared to inflow (blue dot line) at the 1st sampling event

Phase 2: Short-term operation

The 2nd sampling event took place 3 months after the biofilters had been commissioned. This allowed sufficient time for microbial communities to establish in the biofilter. Physical adsorption capacity of the filter media would generally have been exhausted if not regenerated. Odour removal at this stage would be a result of combined physical adsorption/chemical reactions and biodegradation. Based on olfactometric method, there was no different in terms of odour removal efficiencies as almost complete odour removal was achieved in all biofilters. Detailed analysis by GC-MC reveals that air stream from the local composting facility contained a complex mix of over 40 different organic components (Table 3), with terpenes (in particularly limonene) and carbonyl compounds accounting for around half of the organic compounds. This is comparable to the findings by Pierucci et al. (2005) and Smet et al. (1999) that the main gaseous compounds emitted from composting facility are hydrocarbon, including hydrophobic terpenes and hydrophilic alcohol. Both zeolite and coir were found to be effective in removing organic compounds from the waste air stream. As expected high removal efficiency was achieved with water soluble and easily biodegradable compounds such as alcohol, nitrogen and sulphide compounds. Other compounds such as non-water soluble VOCs were also found to be removed by coir and zeolite biofilters. The higher VOC removal efficiency of Biofilter 4 (with inoculum) over biofilter 2 (without inoculum) indicates that inoculum may be beneficial when zeolite was used as filter media.

Table 3 Detail quantification of volatile organic compounds (VOCs) in input and outflow from the biofilters at the 2nd sampling event

Organic compound classes	Inlet	Biofilter 1		Biofilter 2		Biofilter 3		Biofilter 4	
	ppbv	ppbv	%	ppbv	%	ppbv	%	ppbv	%
Nitrogen compounds	**318.6**	**67**	**79**	**206.2**	**35**	**27.8**	**91**	**30**	**91**
Acetamide	318.6	67	79	206.2	35	27.8	91	30	91
Carbonyl compounds	**513.7**	**151.8**	**70**	**234.9**	**54**	**182.9**	**64**	**149.1**	**71**

Acetone	60.4	78.7	-30	80.2	-33	102.4	-70	75.3	-25
2-Butanone	236	1.3	99	67.7	71	0	100	0	100
2 and 3-Pentanone	33.5	3.7	89	0	100	3.9	88	1.2	96
Hexanone *	29.5	0	100	0	100	0	100	0	100
carbonyl compound	89.4	68.1	24	87	3	76.6	14	72.6	19
acetic acid methyl ester	19.7	0	100	0	100	0	100	0	100
2-butanone, 4-hydroxy	45.2	0	100	0	100	0	100	0	100
Alchohol	**286.4**	**11.9**	**96**	**0**	**100**	**0**	**100**	**1.9**	**99**
Isopropanol	87.5	1.2	99	0	100	0	100	1.9	98
n-Propanol	97.4	0	100	0	100	0	100	0	100
Butanol-2	45.3	0	100	0	100	0	100	0	100
n-Butanol	47.6	10.7	78	0	100	0	100	0	100
1-Butanol-3-methyl	8.6	0	100	0	100	0	100	0	100
Aromatic hydrocarbons	**134**	**54.8**	**59**	**146.4**	**-9**	**95.7**	**29**	**3.6**	**97**
Toluene	26	20	23	37.7	-45	37.5	-44	0.7	97
Benzene, ethyl	3.5	1.9	46	0	100	3.3	6	0	100
Xylene	15.9	5.3	67	25.7	-62	15.5	3	0	100
Styrene	4.4	0	100	10.2	-132	0	100	0.7	84
n-propylbenzene	1.6	1.4	13	2.4	-50	1.3	19	0	100
Toluene, m-& p- ethyl	6.4	0.9	86	8.6	-34	3.1	52	0	100
benzene, 1,2,3-trimethyl	2.7	1.11	59	2.6	4	0.8	70	0	100
Benzene, 1,3,5-trimethyl	4.3	0.82	81	8.3	-93	3.7	14	0	100
Benzene, 1,2,4-trimethyl	18	2.7	85	0	100	5.6	69	0	100
Toluene, o- ethyl	3.1	1.18	62	3.88	-25	2.34	25	0	100
butyl benzene	9.7	5.4	75	12.4	-61	5.7	41	0.8	92
p-cymene	25.8	7.9	69	6	77	5.7	78	0.6	98
propyl toluene	12.6	6.2	51	28.6	-127	11.2	11	0.8	94
Terpenes	**549.6**	**137.9**	**75**	**388.2**	**29**	**168.4**	**69**	**32.3**	**94**
b-Pinene	25.7	3.2	88	0	100	18.7	27	0	100
Sabinene	0.5	0.3	40	0.9	-80	0.7	-40	0	100
a-Pinene	13.2	3.6	73	7.5	43	8.7	34	2.3	83
Citronella	1.2	0.2	83	0	100	0.2	83	0	100
Limonene	353.7	81.1	77	298.1	16	82.6	77	12	97
Cineol	44.7	0	100	10.3	77	0	100	0	100
r-terpinene	24.4	3.1	87	8.5	65	4.1	83	0.4	98
a-terpinene	2.4	1.3	46	2.2	8	0.9	63	0.4	83
other terpenes	83.8	45.1	46	60.7	28	52.5	37	17.2	79
Sulphur compounds	**105**	**7.4**	**93**	**14.5**	**86**	**7.2**	**93**	**7.4**	**93**
Methanethiol	66.3	0	100	0	100	0	100	0	100
Dimethyl sulfide	7.6	7.4	3	7.2	5	7.2	5	7.4	3
Dimethyl disulfide	7.7	0	100	7.3	5	0	100	0	100
Diethyl disulfide	7.3	0	100	0	100	0	100	0	100
Methyl ethyl disulfide	7.6	0	100	0	100	0	100	0	100
Methyl pentyl disulfide	8.5	0	100	0	100	0	100	0	100
Others	154.2	30.1	80	0	100	21.6	86	0	100
Total VOCs	**2061.5**	**460.9**	**78**	**990.2**	**52**	**503.6**	**76**	**224.3**	**89**

Phase 3: Long-term operation

After the biofilters had been fully operated for 9 months, the 3rd sampling event was conducted to determine sustainability of the biofilters. Due to unforseen technical problems, biofilter 4 was terminated. However, as biofilter 4 was originally designed to investigate the need of inoculum when zeolite was used as biofilter media. By this time (9 month), microbial communities on biofilter media should have been fully established (with or without inoculum). As a result, there should be no significant different between biofilter 2 and biofilter 4. The loss of biofilter 4 at this stage should not have any significant effect on this study.

Results from olfactometry (Table 2) show that odour removal efficiency of all biofilters remained high. Some drop of efficiency in Biofilter 2 (zeolite) was observed. Note that although odour strength in the inflow during 2nd and 3rd sampling events was almost the same (Table 2), VOC concentrations of inflow in the 3rd sampling event (total of 4361.8 ppbv- Table 4) were more than twofold of that in the 2nd sampling event (total of 2061.5 ppbv). The composition of the VOCs was somewhat similar (Table 4), with terpenes, alcohol and carbonyl compounds as the main compounds. VOC removal efficiency shows similar results to that of 2nd sampling event, with high removal efficiency of water-soluble alcohol and nitrogen compounds. Biofilter 1 and 3, where coir was used as filter media, exhibited higher VOC removal efficiency, particularly terpenes, compared to biofilter using zeolite as filter media.

Table 4 Summary of detected volatile organic compounds (VOCs) based on new method developed by ChemCentre, in input and outflow from the biofilters at the 3rd sampling event

Organic compound classes	Inlet	Biofilter 1		Biofilter 2		Biofilter 3	
	ppbv	ppbv	%	ppbv	%	ppbv	%
Nitrogen compound	**416.7**	**0**	**100**	**0**	**100**	**0**	**100**
Carbonyl compounds	**945.6**	**367.1**	**61**	**311**	**67**	**251**	**73**
Propyl aldehyde	134.9	85.4	37	78.5	42	73.7	45
Aldehyde	5.1	20.9	-310	13	-155	13.6	-167
Acetone	123.4	201.2	-63	144.5	-17	119.2	3
2-Butanone	167	0	100	0	100	0	100
Ethyl acetate	202	0	100	0.3	100	0	100
Acetic acid	142.8	14.3	90	10.8	92	9.7	93
Acetic acid ester	95.2	7.3	92	15.4	84	16.3	83
Carbonyl compound	10	5.2	48	11.5	-15	6.6	34
Propanoic acid ester	65.2	32.8	50	37	43	11.9	82
Alcohol compounds	**935.6**	**47.9**	**95**	**25.3**	**97**	**21.8**	**98**
Isopropanol	176.8	0	100	0	100	0	100
n-Propanol	183	0	100	0	100	0	100
n-Butanol	5.3	0	100	0	100	0	100
1-Butanol-2-methyl*	8.2	5.6	32	6.1	26	6.2	24
1-Pentanol-2-methyl*	24.1	0	100		100		100
Other alcohol	538.2	42.3	92	19.2	96	15.6	97
Terpenoids	**1657.5**	**37.8**	**98**	**288**	**83**	**39.5**	**98**
a- Pinene	104.4	0	100	49.3	53	0	100
Sabinene	*2.1*	0	100	2.9	-38	0	100
b- Pinene	26.2	0	100	14.8	44	0	100
3-Carene	12.5		100	10.4	17	3.3	74
Limonene	1310	10.6	99	164.3	87	15.3	99
Cineol	118.1	0	100	8.1	93	0	100
r-Terpinene	29.6	0	100	3.2	89	0	100
a-Terpinene	12.1	0	100	0	100	0	100

Monoterpene	8.6	3.8	56	9.2	-7	6.3	27
Mono terpenoid	33.9	23.4	31	25.8	24	14.6	57
Aromatic hydrocarbon	**230.8**	**52.4**	**77**	**198.1**	**14**	**109.4**	**53**
Toluene	19	23.4	-23	16	16	8.8	54
Benzene,ethyl	4.7	0.4	91	5.7	-21	1.8	62
Xylene,m & p-	21	5.4	74	24	-14	17	19
Styrene	19.2	3.8	80	13.5	30	7.5	61
Xylene, o-	4.2	2.5	40	5.8	-38	5.7	-36
Isopropylbenzene	1.1	0	100	1.1	0	0.9	18
n-Propylbenzene	3.2	0	100	23	-619	2.5	22
Tolene, m,p ethyl	17.6	0.2	99	20.5	-16	10.5	40
Benzene,1,2,3-trimethyl	5	0	100	0	100	1.2	76
Benzene,1,3,5-trimethyl	5.5	1.2	78	6.9	-25	4.4	20
Tolene, o- ethyl	4.3	0.6	86	4.6	-7	3.1	28
Benzene,1,2,4-trimethyl	28	1	96	29	-4	12	57
p-Cymene	39.7	0	100	7.2	82	1.4	96
Benzene, butyl	17.1	2.1	88	7.1	58	2.6	85
Tulene, propyl	24	0	100	19.4	19	11.7	51
Benzene, butelene	9.4	11.3	-20	8.3	12	14.5	-54
Benzene, pentyl	7.8	0.5	94	6	23	3.8	51
Ether	**51.4**	**58.2**	**-13**	**62.5**	**-22**	**48.7**	**5**
Ethyl methyl ether	41	58.2	-42	56.4	-38	48.7	-19
Dipropyl ether	7.01	0	100	6.1	13	0	100
Ether	3.37	0	100	0	100	0	100
Sulphur compounds	**1.7**	**0.6**	**65**	**1.1**	**35**	**0.4**	**76**
Dimethyl sulfide	1	0.4	60	0.9	10	0.4	60
Dimethyl disulfide	0.7	0.2	71	0.2	71	0	100
Others	**122.5**	**87**	**29**	**111.4**	**9**	**70.3**	**43**
Butane*	69.6	84.8	-22	73.1	-5	68.3	2
1,4-pantadiene*	7.7	0	100	7.2	6	0	100
Cyclopetene,4,4-dimethyl*	4.1	2.2	46	31.1	-659	2	51
Anthacene,1,2,3,4,6,7,8,9-octahydro-2,2,5 trimethyl	41.1	0	100	0	100	0	100
Total VOCs	**4361.8**	**651**	**85**	**997.4**	**77**	**541.1**	**88**

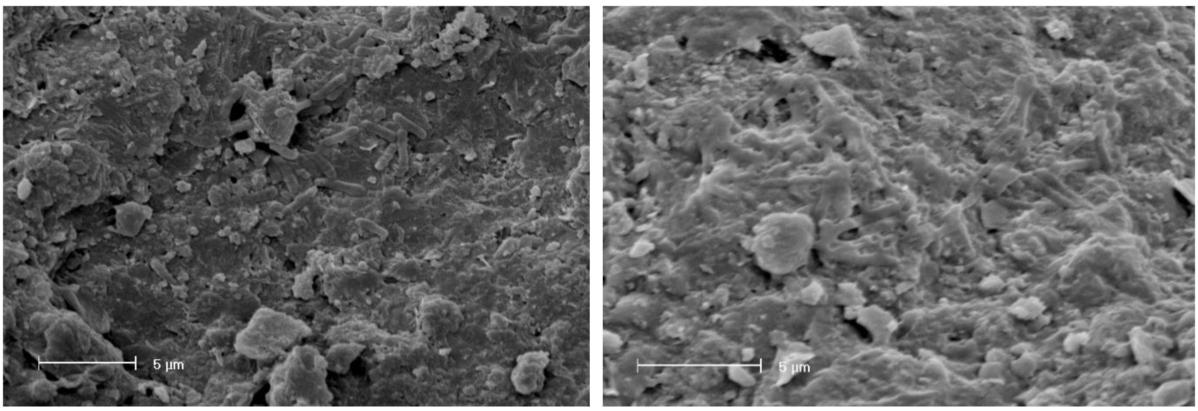

Figure 3: Electron microscopy images of biofilm on the surface of zeolite (left) and coir (right) of filter media samples taken during the 3rd sampling event

The fact that after 9 months from the start up of biofilters, VOC removal efficiency of the biofilters remained high indicates that microbial communities that were able to degrade VOCs from the gas stream were successfully established in the biofilters. To confirm this samples of filter media were taken for electron microscopy. Figure 3 clearly shows biofilm fully covered the surface of both zeolite and coir.

CONCLUSIONS

Biofilters using coir and/or zeolite as filter media were able to significantly remove odour from composting facility waste air stream. While zeolite was effective in adsorbing polar compounds, coir was found to be particularly effective in capturing non-polar VOCs, including monoterpenes, which are the main component in composting waste air stream. The combination of coir and zeolite is beneficial during start up of biofilter when microbial communities have not yet fully established in the biofilter. Overall, zeolite biofilter exhibited slightly lower VOC removal compared to coir biofilter, however it is non-biodegradable and therefore reduces the cost of replenishing filter media in long-term operation. Coir on the other hand demonstrated higher VOC removal, but is biodegradable and will require regular replacement.

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