CHEMICAL ENGINEERING TRANSACTIONS

VOL. 40, 2014

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editor: Renato Del Rosso

ISBN 978-88-95608-31-0; **ISSN** 2283-9216

DOI: 10.3303/CET1440038

Assessment of Odour and VOC Depuration Efficiency of Advanced Biofilters in Rendering, Sludge Composting and Waste Water Treatment Plants

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Stringent requirements of ambient air quality regarding odour concentration levels are being implemented worldwide. Frequently, the conventional technologies available (scrubbers, conventional biofilters, activated charcoal filters…) are unable to achieve the required emission or immission limits when these are very stringent due to the presence of vulnerable receptors in the vicinity. High Performance odour abatement technologies, such as Advanced Biofilters or Thermal Oxidation, have been developed and applied in order to overcome these limitations. The Advanced Biofiltration systems can achieve better odour removal efficiencies (besides other enhanced capabilities) than conventional ones, allowing a suitable depuration of the odoriferous emissions.
In this work we have conducted an assessment of the performance of 3 Advanced Biofilters used for the treatment of odour emissions and removal of VOCs from: a) an Animal Waste Rendering Plant in Hamar, Norway (where an Advanced Biofilter was installed in 2008 that has successfully minimized important odour-related problems) b) a Municipal Waste Water Treatment Plant in Middelfart, Denmark (treating an emission of 1,500m^3/h) c) a WWTP sludge Composting Plant in Mallorca, Spain. Thus, several parameters were measured at the inlet and at the outlet of such biofilters: odour concentration was measured by means of dynamic olfactometry in order to determine their odour reduction efficacy. Ammonia and hydrogen sulfide concentrations were determined as well. Speciated VOC analyses were performed in order to assess the reduction efficacy regarding significant odoriferous VOCs.

1. Introduction

Odour emissions from environmental treatment facilities (such as composting, biomethanisation, rendering, sludge thermal drying and wastewater treatment plants) are frequently the cause of nuisances in their surroundings. Due to the increasing attention paid to these odour episodes, authorities worldwide are implementing stringent requirements of ambient air quality regarding odour concentration levels. In many cases, the available conventional technologies (scrubbers, conventional biofilters, activated charcoal filters…) are unable to achieve the required emission or immission limits (as can be seen in Table 1), and therefore High Performance odour abatement technologies, such as Advanced Biofilters or Thermal Oxidation, have been developed and applied in order to overcome these limitations and have been installed in many facilities throughout Europe.
The classical biological treatment technologies that are available are biotrickling and conventional biofiltration. Biotrickling's main application is the removal of H_2S and mercaptans from some Waste Water Treatment Plant (WWTP) emissions, while the use of biofiltration for the removal of a wide range of VOC and odour abatement in a variety of environmental treatment facilities (composting, biomethanisation, rendering, sludge thermal drying, WWTPs, landfills…) has substantially grown for the last 30 years. These technologies, however, are not sufficiently efficient to be applied to the treatment of emissions with high

Please cite this article as: Almarcha D., Almarcha M., Nadal S., Poulssen A., 2014, Assessment of odour and voc depuration efficiency of advanced biofilters in rendering, sludge composting and waste water treatment plants, Chemical Engineering Transactions, 40, 223-228 DOI: 10.3303/CET1440038

odoriferous loads, where more efficient technologies are required, as can be seen in Table 1. Due to the high operation costs of Thermal Oxidation and other high performance technologies, Advanced Biofiltration technologies have become a good option in these situations. A comparison of the performance of Conventional and Advanced biofilters can be found in Almarcha et al. (2012).

The support of advanced biofilters consists of an inorganic and an organic phase. The inorganic component gives a greatly improved mechanical resistance, and the organic phase is an ideal medium for the proliferation and fixation of the microorganisms while it also acts as an adsorbent, which helps reducing the effects of the variability of the inlet composition and concentrations.

The previously sterilized support of an Advanced Biofilter is inoculated at manufacturing with specific, genetically selected, natural microorganisms, chosen so that they form a consortium tailored to achieve a proven efficiency for every type of application. An “in-situ” pilot test treating real emissions, using detailed knowledge of the composition of the emission and the biomedium manufacturer’s more than 22 years of experience, is carried out for new types of applications. The inoculation is carried out with the selected microorganism strains which are kept isolated in liquid N_2. In the case of applications that the manufacturer has previously worked with, the microorganisms are selected from the manufacturer’s strain collection according to past experience.

The microbiological population of the biomedium is assessed several times each year, and the number of original strands and total strands are checked. According to the manufacturer’s experience, results show that the amount of original strands is always high, due to the fact that they are adapted to the biofilter’s specific conditions, which makes it difficult for extraneous microorganisms to compete.

The advanced biomedia also has a buffering capacity that allows these different types of microorganism to thrive and develop together and avoid the proliferation of pH extremophiles. Some of the microorganisms will be useful for their H_2S removal capacity, while others are capable of destroying sulphur and nitrogen compounds and most other odorous compounds.

As an example of the applicability of this technology, a summary of treatment efficiency results found in the bibliography for a number of Conventional and Advanced Biofilters used in Rendering Plants is included in Table 1. It must be noted that the Best Available Techniques (BAT) Reference Documents (BREF) on slaughterhouses and related industries describes the characteristics that a Biofilter must have in order to be used in this kind of plant, and that these characteristics match what was already implemented in Advanced Biofilters.

Table 1: Summary of bibliographic references on odour removal systems used in animal waste rendering

Reference	Origin of the influent	Flow	Biofilter/biomedia	Inlet (ou_E/m^3)	Efficiency
Anet et al. (2012)	Ambient air	50,000	Peat & Heather	1,000-22,000	72-95%
Anet et al. (2012)	Fat press & Cookers	50,000	Peat & Heather	13,000-12,3000	51-85%
Anet et al. (2012)	Fat press & Cookers	50,000	Peat & Heather	14,000-184,000	62%
Luo&V.Oostrom, (2007)	No data	No data	Bark/Soil & Bark	490,000	75%-87%
Luo&V. Oostrom (2007)	No data	No data	Bark/Soil & Bark	1,100,000	88%-91%
Sironi et al. (2007)	No data	No data	No data	1,000-22,000	73%-80%
Anet et al. (2012)	No data	No data	Peat & Heather	No data	72-95%
BREF (Slaughterhouses & similar Industries)		100,000	Advanced	89,334-103,213	97%-98%
Reference	**Origin of the influent**	**Flow**	**System**	**Inlet (ou_E/m^3)**	**Efficiency**
Sironi et al. (2010)	No data	No data	Steam boiler	No data	91%-99%
Sironi et al. (2010)	No data	No data	Therm.Combustor	No data	93%-99%
Sironi et al. (2010)	No data	No data	Scrubber	No data	30%-83%

2. Materials and methods

A number of samples were analyzed and a VOC screening was conducted in order to compare inlet and outlet compound profiles of advanced biofilter and to determine the elimination efficiencies for different representative compounds. Other parameters were also determined: ammonia, hydrogen sulphide, mercaptans and odour concentration. More details on the methodologies can be found in the next section.

2.1 VOC analyses

Calibration curves and relative response factors to an internal standard were calculated for a list of odorous VOC which are usually present in this kind of samples, such as: reduced sulphur compounds, alcohols, ketones, aldehydes, esters and terpenes, among others. HRGC-MS was also performed by means of various techniques, such as Solid-Phase Microextraction (SPME) or Thermal Desorption, which, used together, allowed to obtain a full VOC profile for each case. Further details on sampling and HRGC-MS analysis can be found in Almarcha et al. (2012).

2.2 Odour concentration

Sampling and dynamic olfactometry odour concentration measurements were carried out as per the Norm EN-13725:2003: "Air quality Determination of odour concentration" in accredited laboratories**.**

2.3 NH_3, H_2S and Mercaptanes

Gas samples were taken in Tedlar bags and then passed through an absorbent solution: H_2SO_4 0.05M for NH_3 analysis and Cd^{2+} in NaOH 0.05M for H_2S and mercaptans. Analyses were performed by UV-Vis spectrophotometry.

3. Results and discussion

The results that were obtained during the assessment of the behaviour of different advanced biofilters used for the treatment of emissions from a WWTP, an urban solid waste composting plant and a rendering facility are presented in this section.

3.1 Animal Waste Rendering Plant

The results shown in this section correspond to an Animal Waste Rendering Plant in Hamar, Norway, where the performance of one of the three Advanced Biofilters installed in the plant was studied. This Biofilter is used to treat an emission with a flow rate of 60,000 m^3/h and high odoriferous loads of around 50,000-65,000 ou_E/m^3. A pretreatment of the emission is carried out in order to remove fat from the system by means of a specialized separation device.

For each of the analytical parameters, 5 samples were analyzed at the inlet of the Biofilter and 5 at the outlet. The results of the speciated VOC analyses are included in Table 3 and odour concentration and other parameters measured at the inlet and outlet of the mentioned Biofilter are shown in Table 2. Figure 1 shows the TIC chromatogram obtained by SPME-HRGC-MS of one inlet and one outlet sample.

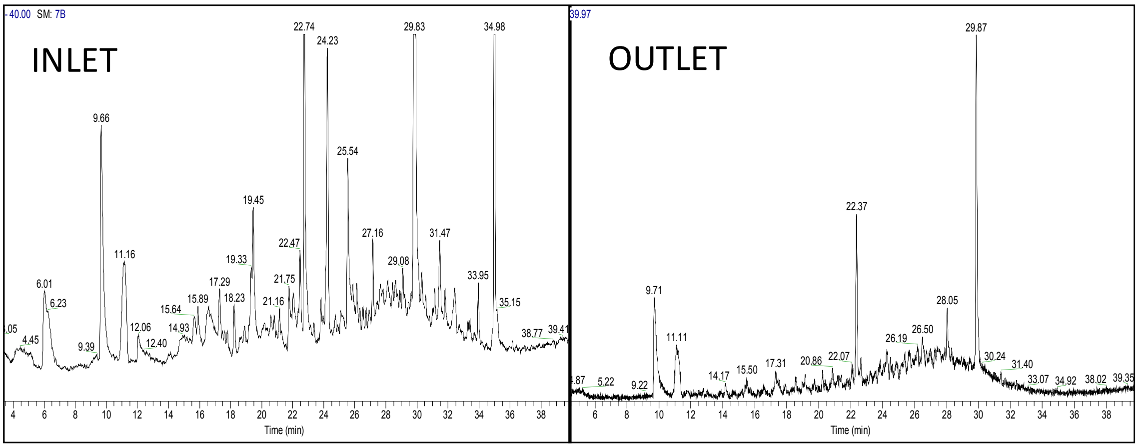

Figure 1: TIC chromatograms of the VOC analysis of inlet and outlet samples of an Advanced Biofilter treating emissions from an Animal Waste Rendering Plant

Table 2: Odour concentration, NH_3, H_2S and Mercaptans (RSH) values at the inlet and the outlet of an Advanced Biofilter in a Rendering Plant.

Parameter	Mean inlet conc.	RSD %	Mean outlet conc.	RSD %	% Reduction
Odour conc. (ou_E/m^3)	61,800	35.2	480	28.9	99
NH_3 (ppm)	27.5	19.4	<0.2	n.a.	>99
H_2S (ppm)	29.5	21.9	<0.2	n.a.	>99
RSH (ppm)	1.4	24.0	<0.2	n.a.	>86

n.a.: not applicable (all the results were lower than the detection limit)

Table 3: VOC results at the inlet and the outlet of an Advanced Biofilter in a Rendering Plant.

Compound	Mean inlet conc. (µg/m³)	Mean outlet conc. (µg/m³)	% Reduction
Trimethylamine	3,559.6	256.7	93
Methanethiol	248.5	18.4	93
3-Methylbutanal	3,499.0	21.4	99
2-Methylbutanal	2,807.8	19.8	99
Dimethyl disulfide	186.7	<2	>99
Hexanal	743.6	<2	>99
Hexanoic acid	255.6	<2	>99
2-Heptanone	557.8	29.7	95
Heptanal	794.3	<2	>99
2,5-Dimethylpyrazine	754.8	15.9	98
3-Methylbutanoic acid	413.3	<2	>99
Aldehyde C7 or C8	64.1	<2	>97
2-Pentylfuran	582.3	18.6	97
Dimethyl trisulfide	98.5	<2	>98
Alcohol C7 or C8	161.0	8.0	95
2-Octanone	272.9	42.6	84
2-Ethyl-6-methylpyrazine	917.3	23.6	97
Octanal	2,310.5	15.5	99
4-Methylpentanoic acid	189.6	<2	>99
2-Ethylhexanol	284.0	<2	>99
1-Methylpyrrole	155.6	4.3	97
3-Ethyl-2,5-dimethylpyrazine	826.7	10.2	99
1-Octanol	515.5	56.9	89
2-Nonanone	805.9	48.6	94
Nonanal	3,863.9	89.1	98
Butyl hexanoate	468.3	6.4	99
Aldehyde C9 or C10	260.6	144.9	44
Aldehyde	118.1	15.7	87
2-Decanone	1,596.8	74.5	95
Decanal	427.6	8.9	98
Alcohol	157.0	34.0	78
2-Undecanone	251.6	41.5	84
Pyrazine	63.8	<2	>97
2-Octanone	272.9	42.6	84

Relative standard deviations (RSD) for the analyzed VOC were in the ranges of 25-46 % for the inlet and 23-51 % for the outlet.

3.2 WWTP Sludge Composting Plant

The results shown in this section correspond to an advanced biofilter treating emissions from a WWTP Sludge Composting Plant in Mallorca, Spain. All of the air of the different halls and processes of the composting facility is treated in an Advanced Biofilter installed in 2003, which is designed to treat 15,000 m^3/h of air from pretreatment and compost refining (average odour concentration was 2,200 ou_E/m^3), 43,000 m^3/h of air from loading and unloading of the composting tunnels hall, (odour concentration of 1,200o ou_E/m^3), and 50,000 m^3/h from the composting tunnels (odour concentration was 28,000 ou_E/m^3).
For each of the analytical parameters, 6 samples were analyzed at the inlet of the Biofilter and 4 at the outlet. The results are included in Tables 4 and 5.

Table 4: Odour concentration, NH_3, H_2S and Mercaptans (RSH) values at inlet the outlet of an Advanced Biofilter in a WWTP Sludge Composting Plant

Parameter	Mean inlet conc.	RSD %	Mean outlet conc.	RSD %	% Reduction
Odour conc. (ou_E/m^3)	10,083	21.5	528	27.1	95
NH3 (ppm)	7.1	17.7	<0.2	n.a.	>97
H2S (ppm)	<0.2	n.a.	<0.2	n.a.	--
RSH (ppm)	<0.2	n.a.	<0.2	n.a.	--

n.a.: not applicable (all the results were lower than the detection limit)

Table 5: VOC results at inlet and outlet of an Advanced Biofilter in a WWTP Sludge Composting Plant

Compound	Mean inlet conc. (μg/m^3)	Mean outlet conc. (μg/m^3)	% Reduction
Acetone	12.6	<2	>84.1
Dimethyl sulfide	10.1	<2	>80.1
Methyl acetate	27.8	<2	>92.8
2-Methylfuran	15.7	<2	>87.3
2-Butanone	154.1	39.9	74.1
3-Methyl-2-butanone	22.3	<2	>91.0
2-Pentanone	5.5	<2	>63.6
3,3-Dimethyl-2-butanone	15	<2	>86.7
Dimethyl disulfide	205.3	<2	>99.0
Butyl acetate	137.2	<2	>98.5
Pentyl acetate	14.6	<2	>86.3
4-Methyl-2-pentanone	13.6	<2	>85.3
4,4-Dimethyl-2-pentanone	10.9	<2	>81.7
2-Hexanone	22.3	4.8	78.5
Hexanal	45.5	<2	>95.6
Methyl propyl disulfide	10.2	<2	>80.4
Possible 3-Heptanone	9.9	<2	>79.8
Possible cyclohexanemethanol	8.0	<2	>75.0
α-Pinene	2,010.7	235.5	88.3
Camphene	80.4	<2	>97.5
2-β-Pinene	600.8	89.0	85.2
Limonene	2,430.4	358.9	85.2
p-Cymene	883.0	170.8	80.7
Alcohol	213.9	<2	>99.1
Terpene	218.3	13.9	93.6

Relative standard deviations (RSD) for the analyzed VOC were in the ranges of 18-49 % for the inlet and 15-40 % for the outlet.

3.3 Waste Water Treatment Plant

Middelfart Municipal Waste Water Treatment Plant treats urban wastewater from the town of Middelfart in Norway. In 1999, an Advanced Biofilter was installed in this WWTP in order to treat emissions from the water reception and primary treatment areas. It is designed to treat a total flow of 1,500m^3/h.

For each of the parameters, 4 samples were analyzed at the inlet of the Biofilter and 5 at the outlet. The results of the speciated VOC analyses, odour concentration and other parameters at the inlet and outlet of the mentioned Biofilter are included in Tables 6 and 7.

Table 6: VOC results at inlet the outlet of an Advanced Biofilter in a Waste Water Treatment Plant

Compound	Mean inlet conc. (μg/m^3)	Mean outlet conc. (μg/m^3)	% Reduction
Dimethyl sulfide	106.5	14.9	86
2-Butanol	279.3	<2.0	>99
Ethyl acetate	516.8	<2.0	>99
Dimethyl disulfide	163.2	<2.0	>99
Ethyl butanoate	540.5	<2.0	>99
Butyl acetate	624.1	<2.0	>99
Pentyl acetate	242.6	<2.0	>99
2-Heptanone	138.9	30.6	78
α-Pinene	1,012.9	104.6	90
2-β-Pinene	850.4	113.2	87
2-Pentylfuran	84.5	<2.0	>98
Alcohol	440.7	<2.0	>99
Possible aldehyde	254.6	18.8	93
p-Menthan-9-ol	609.0	67.6	89
Limonene	2,987.7	184.3	94
p-Cymene	1,145.8	63.0	95
Eucalyptol	831.1	61.1	93
Alcohol	194.3	25.3	87
Terpene	506.9	<2.0	>99
Alcohol	255.7	10.6	95
Aldehyde	489.5	<2.0	>99

Relative standard deviations (RSD) for the analyzed VOC were in the ranges of 18-49 % for the inlet and 15-40 % for the outlet.

Table 7: Odour concentration, NH_3, H_2S and Mercaptanes (RSH) values and speciated VOC results at the inlet and the outlet of an Advanced Biofilter in a WWTP Sludge Composting Plant

Parameter	Mean inlet conc.	RSD %	Mean outlet conc.	RSD %	% Reduction
Odour conc. (ou_E/m^3)	12,205	30.5	445	24.0	>99
NH_3 (ppm)	<0.2	n.a.	<0.2	n.a.	na
H_2S (ppm)	10.4	15.3	<0.2	n.a.	>98
RSH (ppm)	2.0	20.8	<0.2	n.a.	>90

n.a.: not applicable (all the results were lower than the detection limit)

4. Conclusions

The assessment performed shows that Advanced Biofilters have very high efficiencies (85-99%) for the inorganic (NH_3, H_2S) and organic (VOC) compounds with odour significance typically present in these emissions, though removal efficiencies of a few compounds, such as some terpenes, may be somewhat lower. Odour concentration efficiencies were also very high, in the range of 95-99% or final odour concentrations lower than 500ou_E/m^3.
Furthermore, the results indicate that the removal efficiencies of Advanced Biofilters are comparable to those of other High-Performance technologies, such as Recuperative Thermal Oxidation, for these applications (animal waste rendering, WWTPs and sludge composting facilities).

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