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The effects of biofilter on the removal of greenhouse gases at anaerobic digestion plants

Khả năng loại bỏ khí gây hiệu ứng nhà kính của các bể lọc khí sinh học tại các nhà máy xử lý chất hữu cơ bằng biện pháp kỵ khí

Research article

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This study investigated the removal of gases such as methane (CH4), nitrous oxide (N2O) and ammonia (NH3) from biofilters in nine anaerobic digestion plants in Germany that treat biowaste. The treatment is in form of mechanical pre-treatment, anaerobic digestion followed by a composting with or without intensive aeration. The exhaust gases from the mechanical and anaerobic steps are treated by biofilters. In average, the biofilters removed 30% of total organic carbon (TOC), 50% of non-methane volatile organic carbon (NMVOC) and 51% NH3, whereas N2O concentrations increased by 26%. For CH4 the biofilters had only a small removal effect (6%).

Nghiên cứu khảo sát sự loại bỏ những khí gây hiệu ứng nhà kính như CH_4, N_2O và NH_3 từ những bể lọc khí sinh học ở chín nhà máy xử lý rác thải hữu cơ ở nước Đức bằng các biện pháp kỵ khí và hiếu khí. Rác hữu cơ được xử lý ở nhà máy thông qua các biện pháp như tiền xử lý bằng cơ học, kỵ khí và tiếp theo là hiếu khí với công nghệ thổi khí chủ động hoặc không thổi khí chủ động. Khí thải từ các quá trình cơ học và kỵ khí được xử lý bằng biện pháp lọc khí sinh học trước khi thải ra môi trường. Trung bình, những bể lọc khí sinh học loại bỏ 30% tổng lượng carbon hữu cơ, 50% những chất carbon hữu cơ bay hơi nhưng không phải khí methane và 51% khí ammoniac. Trong khi đó, nồng độ khí N_2O tăng lên 26% sau khi qua bể lọc khí sinh học. Đối với khí methane, bể lọc khí sinh học có hiệu suất loại bỏ với loại khí này rất thấp chỉ 6%.

Keywords: greenhouse gas, emissions, composting, windrows, organic waste, methane, biofilter

1. Introduction

Anaerobic digestion (AD) for treatment of biowaste is rapidly gaining interest in Germany (Mata-Alvarez *et al.*, 2000; Fricke *et al.*, 2005). The treatment is essentially based on the activities of microorganisms that transform organic substances into biogas (Appels *et al.*, 2008). Biogas is used as renewable energy source, and nutrients in the residue can be recovered in agriculture as fertilizer or soil conditioner (Møller *et al.*, 2009). In addition, AD of biowaste is attracting attention as an effective method to reduce greenhouse gas (GHG) emissions according to Kyoto protocol (Møller *et al.*, 2009). According to the life cycle analysis (LCA), AD results in negative GHG emissions. The total GHG emissions for AD can reduce up to one tonne CO_2 equivalent/ Mg separated organic waste (Sanscartier *et al.*, 2011).

Actually, many studies have been conducted to show the benefits of AD treatment, for instance the works of Bockreis and Steinberg (2005), Fricke *et al.,* (2005), Zupančiča, (2008) and Møller *et al.,* (2009). In fact, AD plants may have fugitive emissions of CH_4, N_2O and NH_3.

CH_4 and N_2O are considered to be strong greenhouse gases (GHGs), whereas NH_3 is identified as an odour component and an indirect GHG. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), the global warming potential of CH_4 and N_2O in 100 years are respectively 25 and 298 times higher than CO_2. According to Insam and Wett (2008), CH_4 is the major contributor to GHG emissions from waste treatment. Landfills and waste water are the largest sources of CH_4 emissions, accounting for 90% of CH_4 emissions linked to the waste sector. In developed countries, CH_4 produced in

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landfills is collected and used as a renewable energy source (Bogner *et al.*, 2008).

Exhaust gases from the encapsulated parts of AD plants are treated by biofilters before they are released into the atmosphere. In a biofilter, waste gas passes biofilter material (e.g. wood chip and root bark) and organic compounds are degraded by microorganisms (Hort *et al.*, 2009). The performance of a biofilter depends on the composition of the exhaust gas, packing material, nutrient supply, temperature, pH, pressure drop and residence time (Deshusses *et al.*, 1999).

The aim of the study was to investigate the biofilter's efficiency. The biofilters in nine operating AD plants in Germany, two wet digestion plants, four dry digestion plants and three solid digestion plants, were evaluated.

2. Materials and methods

2.1 Measured locations

Fifteen biofilters at nine AD plants were investigated in the study. The gas before and after biofilter was analysed at each plant for 1 week. At capsuled biofilters the treated air left the biofilter in a chimney. Here the gases were measured. At open biofilter, 16m^2 of the biofilter (4x4m) was covered by a thin foil. Concentrations of the treated gases were measured under the foil (Figure 1).

At two AD plants, acid scrubbers were used to eliminate NH_3. High NH_3 concentrations in the raw gas should be removed by acid scrubbers. To evaluate the NH_3 and other gases such as TOC, CH_4 and N_2O removal efficiencies of the acid scrubbers. The concentrations of NH_3, TOC, CH_4 and N_2O at the inlet and outlet of the acid scrubbers were measured.

2.2 Emission determinations

Continuously monitored parameters included TOC, CH_4 and N_2O. TOC was measured by flame ionisation detector (FID) (Bernath Atomic 3006) while CH_4 and N_2O were measured by an infrared gas analyser (ABB). Gas concentrations in the treated and untreated exhaust air were recorded every minute. To control the accuracy of the infrared gas analyser, exhaust gases were sampled manually by evacuated headspace vials and subsequently analysed on CH_4 and N_2O by gas chromatography (ECD/FID) in the laboratory. A manual discontinuous analysis was applied for NH_3 measurement: NH_3 was extracted from the waste gas stream by absorbing it in sulfuric acid and subsequently measured colorimetrically in the laboratory. NH_3 samples of treated and untreated gases were collected twice. Air fluxes to the biofilter were measured by an anemometer (testo 435) or micromanometer (Müller Instruments EPM-300-BA, Germany). It was assumed that the volumes of treated and untreated air were the same.

Figure 1: Foil covers on a biofilter for CH_4, N_2O and NH_3 concentration measurements

3. Results and discussion

3.1 The effects of biofilters on the removal of TOC, NMVOC, CH_4, NH_3 and N_2O in waste air at AD plants

The concentrations at the inlet and outlet of the biofilters in form of TOC, NMVOC, CH_4, NH_3 and N_2O are shown in the Figure 2. The concentrations of NMVOC were calculated by subtracting TOC and CH_4-C. Inlet gas contained an average of 151mg/m^3 TOC in the range of 26-333 mg/m^3, an average of 150mg/m^3 NH_3 in the range of 2.4-1,704mg/m^3 and in average of 2.3mg/m^3 N_2O in the range of 0.8-6mg/m^3 and in average of 168mg/m^3 CH_4 in the range of 13-380 mg/m^3 respectively. The results are in line with those found by Amlinger *et al.,* (2008) and Clemens and Cuhls (2003).

Biofilters reduced TOC, NMVOC and NH_3 but were a source for N_2O. Additionally, biofilters reduced CH_4 only slightly. Mean relative reductions were 30, 6, 50 and 51% for TOC, CH_4, NMVOC and NH_3 respectively, whereas N_2O concentrations were 26% higher in treated air. The increase of N_2O may be explained by the fact that NH_3 is converted to N_2O by nitrification due to continuous aerobic conditions in the biofilters (Melse and Van der Werf, 2005). According to previous studies, around one third NH_3 that enters biofilters can be transformed and released as N_2O (Trimborn, 2003). Similarly, Clemens and Cuhls (2003) reported that 26% of NH_3 was transformed into N_2O in biofilters. The reduction of TOC, CH_4 and NH_3 were lower than in previous studies (Table 1). Ojstrsek and Fakin (2009) found that TOC removal efficiency of biofilters varied from 31 to 75%. Similarly, Soyez (2002) found that 50% of TOC was removed in the biofilter. With regard to other literature, CH_4 was reduced by 15% (Amlinger *et al.*, 2008). NH_3 was removed in biofilters by more than 90% (Soyez, 2002; Chen *et al.*, 2005; Hort *et al.,* 2009; Ryu *et al.*, 2011), whereas Akdeniz (2012) found that the reduction efficiency of NH_3 were from 53 to 64% at full-scale biofilters.

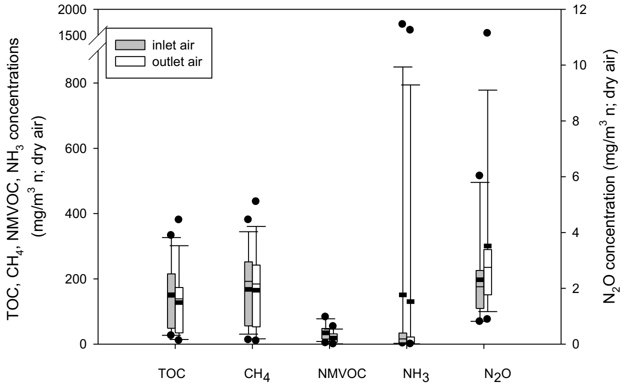

Figure 2. Box plots (n=15) show mean gas concentration values (mg/m^3) of treated and untreated air. Box indicates 25 and 75% percentile; - minimum and maximum of total organic carbon (TOC), methane (CH_4), non-methane volatile organic carbon (NMVOC), ammonia (NH_3) and nitrous oxide (N_2O).

Table 1: Comparison of removal efficiency of biofilters: this study and data from literature

Authors	Removal efficiency of biofilter (%)				
	TOC	**CH_4^***	**NMVOC**	**NH_3^***	**N_2O^***
This study	11 to 70	1 to 25	11 to 100	6.4 to 94	0.1 to -500
(Soyez, 2002)	50	-	83	90	-
(Akdeniz, 2012)	-	-	-	53 to 64	-29.2
(Amlinger *et al.*, 2008)	-	15	-	-	-
(Ryu *et al.*, 2011)	95 to 99	-	-	92	-
(Lopez *et al.*, 2011)	90	-	-	-	-
(Hort *et al.*, 2009)	-	-	-	94	-
(Chen *et al.*, 2005)	-	-	-	97 to 99	-
(Ojstrsek and Fakin, 2009)	31 to 75	-	-	-	-
(Schlegelmilch *et al.*, 2005)	-	-	-	100	-
(Clemens and Cuhls, 2003)	-	-	-	13 to 89	-
(Trimborn, *et al.,* 2003)	32 to 78	-7 to 26	75 to 100	-35 to 91	-9 to -116

- no data
* negative values mean a production in the biofilter

3.2 Acid scrubber for NH_3 removal

The inlet concentrations of TOC, CH_4, NH_3 and N_2O were 215, 227, 24 and 2.4mg m^{-3} respectively (Figure 3).

Removal efficiency of the acid scrubber was 48% for NH_3. Concentrations of TOC and CH_4 were not significant difference before and after the acid scrubber. Neutral to slightly N_2O formation from NH_3 was found in the outlet gas.

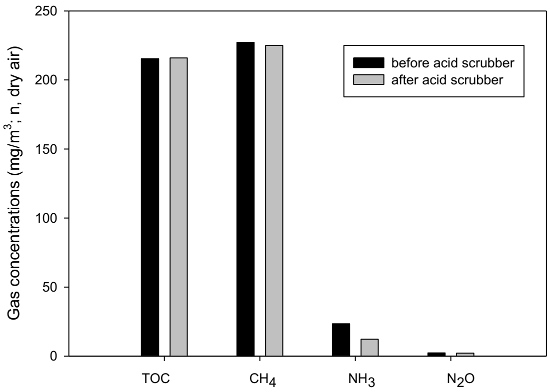

Figure 3. Gas concentrations before and after acid scrubber

3.3 Purification efficiency of biofilters

Biofilters showed only a small influence on CH_4 emission reduction (6%) (Figure 4), whereas they were a source of N_2O emissions (from 0.1 to 500% N_2O was generated in the biofilters). Biofilters removed significantly TOC (30%), NMVOC (50%) and NH_3 (51%).

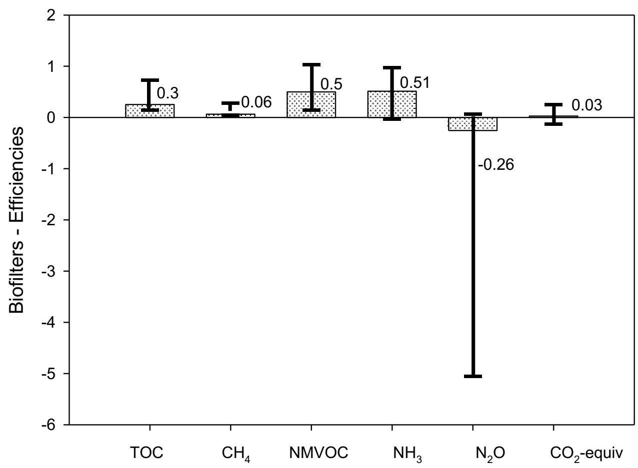

Figure 4. Mean biofilter's efficiencies (n=15) in AD plants. Bars show indicates minimum and maximum values of total organic carbon (TOC), methane (CH_4), non-methane volatile organic carbon (NMVOC), ammonia (NH_3) and nitrous oxide (N_2O).

The purification efficiency of the analysed biofilters differed. According to IPCC (2007), the emission factors were transferred into CO_2 equivalents. Five of fifteen investigated biofilters resulted in higher CO_2 equivalents Mg^{-1} in the exhaust gas as compared to the untreated gas. These five biofilters increased the overall CO_2 emissions from 8 to 16% due to additional N_2O production. The other ten biofilters showed a positive CO_2 equivalents balance and reduced GHG by 0.02 to 21%.

4. Conclusions

In conclusion, biofilters showed an influence on TOC, NMVOC and NH_3. However, N_2O is generated significantly and is the major contributor to the GHG emissions.

There was no significant difference of the treated and untreated CH_4 concentrations. Therefore, we conclude that biofilters could not eliminate CH_4 concentrations in waste gas.

Biofilter treatment alone shows insignificant GHG emissions reduction. GHG emissions from AD plant can be limited by a combination of acid scrubber and biofilter.

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