Biotrickling Installations applied for the Treatment of Municipal and Industrial Air Pollutions.

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Abstract
Many lab-studies have been conducted and described on biotrickling filtration, but not many full-scale biotrickling applications have been realized. Biological air treatment methods like biotrickling are very efficient in the removal of different pollutants like for example reduced sulfur compounds without the use of chemicals. Biotrickling installations can be used to treat large air streams in reactors with a relatively small footprint. This presentation describes successful applications of biotrickling installations treating reduced sulfur compounds at different industrial processes.

Keywords:
Biotrickling, full-scale applications, VOSC, mercaptans, CS_2, H_2S.

INTRODUCTION

In recent years, biological techniques have been applied more frequently for industrial applications, because they eliminate many of the drawbacks of classical physical-chemical techniques (Groenenstijn en Hesselink, 1993; Kraakman, 2001).

The disadvantages of the traditionally used air-treatment techniques are high-energy costs (incinerators), the use of chemicals (chemical scrubbers) and the production of waste products (incinerators, scrubbers, active-carbon).

Conventional organic media biofilters have been often applied to treat very different types of air streams. Although there have been a lot of failures, many of these installations have been successful to treat polluted air. Conventional biofilters have serious limitations though in treating polluted air streams that contain compounds:

- which are difficult to degrade biologically (e.g. large molecules, PACs, chlorinated compounds),
- that are very poorly soluble in water (e.g. hexane, pentane ,1-3-butadiene),
- which result during the degradation in a build-up of intermediates like catachols and acids like acetic acid,
- which gives acid degradation products (e.g. sulfur and nitrogen compounds).

A disadvantage of conventional biofilters is that the organic media needs to be replaced every 3 to 5 years. The costs for the replacement of media can be up to 40% of the operational cost (Bioway data, not shown). When space is restricted conventional biofilter systems can be another disadvantage, because it needs a relatively large amount of space when compared to other air treatment techniques.

A lot of effort has been done over the recent years to improve ease the technology of biological air purification. Progress has been made in research fields like microbiology, biofilm or biofilter modeling and new reactor designs. Examples of this are the use of thermophilic micro-organisms, the degradation of chlorinated compounds (Seignes, 2000), degradation of NOx (Woertz et al., 2001), biofilter applications with fungi (Groenenstijn et al., 2001; and Kraakman et al., 1997), the use of predators to prevent clogging (Cox, H.H.J. et al., 1999a and Woertz et al., 2002), the progress in fields like biofilm and biofilter modeling (Picioreanu et al., 1999 and Alonso et al. 1998) and reactor design and reactor-operation with or without using additional techniques (Song and Kinney, 2000, Cox and Deshusses, 1999b, Melse and Kraakman, 1998).

This presentation describes different successful case studies of biotrickling installations applied at different industrial processes.

METHODS

Biotrickling filters

The biotricklingfilter systems have multi layers of media to reduce the risk of airflow channeling and to allow irrigation of each layer separately. The process water in the biotricklingfilter can be recirculated. The inorganic media (a proprietary product) is used to obtain an optimal interaction between the gas phase and the biofilm and to provide a durable operation of the reactor. The pH is often automatically controlled and the biotrickling contains at industrial sites a controllable interface system for the operator. The biotrickling systems studied here have been described earlier by Kraakman (2001). The sizes and the footprints of the biotricklingfilters of the different case studies are mentioned as well as the type of air that is treated in the biotrickling filter.

The biotricklingfilters at wastewater treatment plants and lift stations have to treat odorous air streams which are often small (mostly up to <10.000 m3/h). The composition of the compounds is relatively constant although concentrations fluctuate in time. High removal of the odours a.o. hydrogen sulphide and other reduced sulfur compounds (VOSC) like mercaptans are required. The operation of the biotricklingfilter should be able to function with or without a fan. When functioning without a fan the air comes out a dwell only when wastewater enters the dwell. Low-pressure drop over the biotricklingfilter is therefore required. Low maintenance and the simplicity of operation are important for this type of application.

Air streams emitted by viscose industries contain CS_2 in combination with H2S. The volume of the streams is relatively large (> 50.000 m3/h) and CS_2-emissions form the driving force to treat them. The emissions of CS_2 are regulated in many countries and conventional air treatment techniques are often not cost effective. It is important that the air is treated at any time and special requirements for the biotricklingfilter are necessary because of the explosion danger of CS_2. The process control is much more complicated and special training for the operators is required.

Microbiology

The biotrickling filters in Case study 1 and Case study 2 were treating pollutants from respectively aerobic and anaerobic wastewater treatment plants. They were inoculated with activated sludge from at least two different wastewater treatment systems, always from one system at the site where the biotrickling filter is located.

The biotrickling filters (in case study 3) treating CS_2 emissions were inoculated with bacteria which were grown in a chemostat system. The bacteria degrade CS_2 via carbonyl sulphide (COS) and H_2S to form sulphuric acid. The chemolitho-autotrophic microorganisms are acidophiles that can degrade CS_2 at pH < 1. The microbiological characteristics of these bacteria are not discussed here and will be described elsewhere. The biotricklingfilters are operated at low pH in order to concentrate the produced sulphuric acid.

Robustness

When biological air treatment techniques are applied in industries where air pollution control is very strictly regulated, a good control of the biological systems is prerequisite. To be able to operate a biofilter system constantly at optimum conditions a good understanding and a good control of the important process conditions in a biofilter system is necessary. A way to limit the risks of biological air treatment is to determine its robustness.

Robustness can be defined to reflect the ability of the biological system to deal with fluctuations and the ability to recover after operational failures. Biological systems are influenced by parameters such as pH, water content, temperature and concentrations of the carbon sources, energy sources and nutrients. The robustness of biological systems can be demonstrated with well-designed experiments in the laboratory or with pilot- and full-scale experiments in an industrial environment.

Quantification of the robustness of a biological air purification system would be helpful to designers and operators of these systems.

Robustness may be quantified by determining the risk of negative effects on the biological system for each possible upset, multiplying by the frequency of the upset, and summing over all possible upsets.

The risk of negative effects on a biological system (R) can be defined as:

$$R = \Sigma(p \times E)$$

p = the probability of occurrence of a fluctuation
E = the negative effect of the fluctuation

The probability of occurrence of a fluctuation (p) can be expressed as the expected number of occurrences per year (number/year) or as the percentage of operating time during which it is likely to occur. The negative effect of the fluctuation (E) can be expressed as the loss of the removal efficiency (%), the loss of the total removal (kg/day or kg/year), or the impact on the people living near the installation (e.g. the number of occurrences during which the concentration of the emitted air stream exceeded the odor threshold in the neighborhood).

Calculation for a hypothetical example: *The robustness of a biological air purification system after a monthly maintenance shutdown: The* CS_2 *concentration of an 80,000* m^3*/h air stream varies between 400 and 800 mg/*m^3 *with an average of 650 mg/*m^3 *during the day. The biological air treatment system is designed for this routine fluctuation and the overall removal efficiency is > 90%. Every month the production process has to be shut down for 1 day because of maintenance activities in the production process. The removal efficiency after the restart is 40% and increases linearly over 24 hours to 90%. The probability of occurrence (p) = 1/month. The negative effect (E) is a lower removal efficiency following the maintenance shutdown: 80,000 x 650 x ((90-(40+90)/2)/100) x 24= 312 kg for each maintenance shutdown. The total yearly removal capacity is 12 x 312= 3744 kg per year. Assuming that the biological air purification system is operated 52 weeks a year continuously, the risk is 0.91% loss of total removal per year.*

The microbiological community in the system must face fluctuations related to the production process (changes of air inlet concentrations and air conditions such as flow and temperature. These fluctuations result from continuous or discontinuous processes, irregular unplanned shut downs (production process failures), planned shut-downs (holiday/maintenance) and diurnal fluctuations. There may also be fluctuations related to the operation of the air purification system, for example, associated with loss of control of the nutrient supply, water recirculation flow or the pH of the support medium.

RESULTS AND DISCUSSION

Case study 1

Application: air from sludge tanks, primary clarifiers, aerated balance tanks, buildings and sludge containers at a municipal wastewater treatment plant.

Airflow characteristics:

- flow: 12000 m^3/h, temperatures 30-45°C, humidity: 50-80%;
- H2S-concentrations are 50 ppm (average) and 100 ppm (peak).

Type of biotricklingfilter:

- 3 ZEROCHEM^{TM} biotricklingfilter ZC3600 (see Figure 1);
- footprint biotricklingfilter is 35 m^2 and the filters are operated since 2002.

Removal efficiencies: see Figure 2.

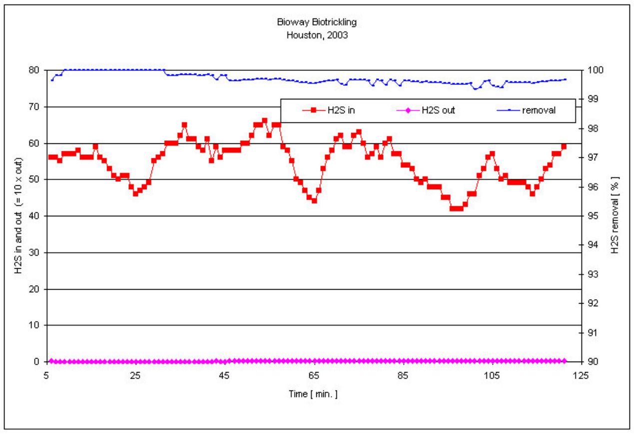

Figure 2: H2S-removal in the biotricklingfilters.

Figure 1: The Biotricklingfilters.

Case study 2

Application: Air from a settlement tank of an anaerobic wastewater treatment plant treating wastewater from a potato processing plant.

Airflow characteristics:

- flow: 300 m^3/h, temperatures 25-35°C, humidity: >90%;
- H2S-concentrations are 350 ppm (average) and 800 ppm (peak).

Type of biotricklingfilter:

- 1 PURSPRING^{TM} biotricklingfilter PS2200;
- footprint biotricklingfilter is 4 m^2 and the filter is operated since 1997.

Removal efficiencies: see Table 1 and Table 2.

Table 1: Removal of odour and reduced sulfur compounds in September 1998.

	Odour (OU/m^3)	H_2S (ppm)	Other VOSC (ppm)
INLET	3500000	769	nd
OUTLET	9667	0,23	nd
Removal (%)	99,72	99,97	nd

nd = not determined

Table 2: Removal of odour and reduced sulfur compounds in July 2003.

	Odour (OU/m^3)	H_2S (ppm)	Other VOSC (ppm)			
			DMS	DMDS	DMTS	MM
INLET	nd	69	0,035	0,011	0,008	0,56
OUTLET	nd	0,7	0,018	0,001	<0,006	0,01
Removal (%)	nd	99,0	48,6	63,6	nd	98,2

nd = not determined

Case study 3

Application: Process air from a cellulosic sponge manufacturing plant

Airflow characteristics:

- flow: 51000 m^3/h, temperatures 25-35°C, humidity: 80-90%;
- CS2-concentrations ranging from 200 up to 400 ppm;
- H2S-concentrations ranging from 200 up to 400 ppm.

Type of biotricklingfilter:

- 6 V-SPRING^{TM} biotricklingfilter PS3750 (see Figure 3);
- footprint biotricklingfilter is 120 m^2 and the system is operated since 1999/2000.

Removal efficiencies and degradation capacities (see Figure 4);

- H2S-removal > 90% (average over 3 year, measured twice a day)*
- CS2-removal > 80% (average over 3 year, measured twice a day)*

*These removal efficiencies are required by the USA EPA.

Figure 3: Biotricklingfilter system for treatment of CS_2 emissions

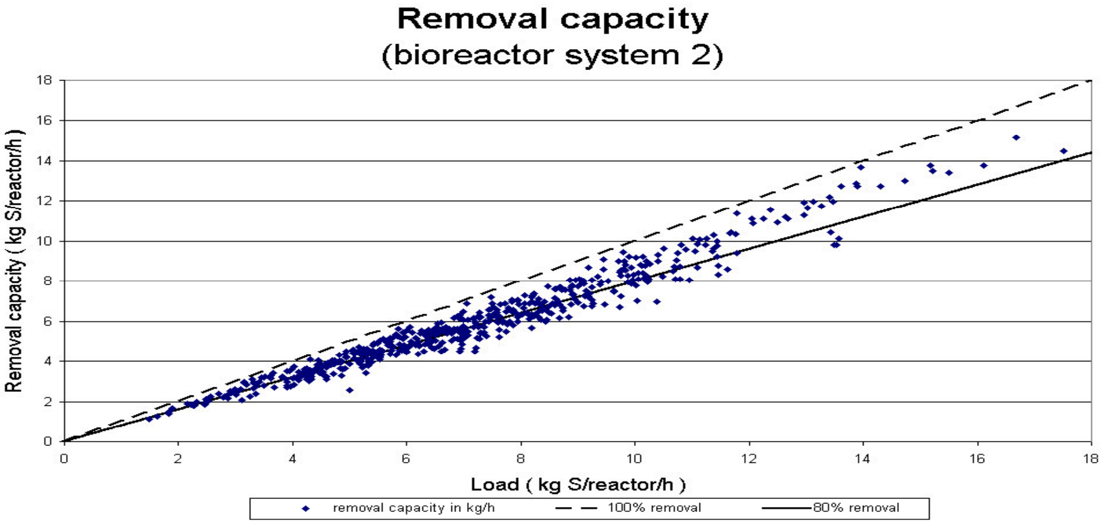

Figure 4: Removalcapacity of a biotricklingfilter system treating CS_2 emissions

Robustness of biotricklingfilter in Case study 3

The biological process in the biotricklingfilter can be exposed to different conditions that can be present at an industrial production plant, because of process failures or operator mistakes.

Table 3: Estimated overall risk (R) of the biotricklingfilter system treating industrial CS_2 emissions. The data are obtained from upsets that were experienced with different installation treating industrial CS_2 emissions over the years (Kraakman, 2003).

Upsets for the microorganisms	**Example**[1]	**p** **(Probability on occurrence)**	**E** **(negative Effect)**	**R** **(Risk = p x E)**
		number per year	% loss of emission removal	% loss of emission removal per year
No energy source	Production stop (8 hours)	6 per year	0.22	1.32
	Weekend shutdown (2 days)	2 per year	0.44	0.88
	Holiday (9 days)	2 per year	0.70	1.40
Fluctuations of energy source	< +/- 25% of daily average CS_2 load during the week	every day	0	0
	< +/- 50% of average CS_2 concentration during the day	all the time	0	0
No water	Broken water valve /temporary no water source (1 day)	1 per year	0.15	0.15
No nutrients	Broken nutrient dosingpump(1day)	1 per year	0	0
Out of temperature range	Inlet air temperature too high	0 per year	4	0
	Inlet air temperature too low	0 per year	< 0.5	0
TOTAL RISK				**3.75**

[1] Examples experienced at different biotricklingfilters treating industrial CS_2 emissions

In a recent study (Kraakman, 2003) the loss of the total removal (kg/year) was used to express the negative effect of a fluctuation in order to illustrate the risks to the waste gas purification. Failures like no water, no electricity, no process air, no nutrients, high temperatures and production interruptions because of holidays or the annual plant maintenance were investigated and showed that the biological process is very well capable of treating CS_2-emissions under different circumstances. Experience indicates that the overall risk for operating this system is less than 4% loss of total removal per year (see Table 3). Therefore it is concluded that this system is a reliable technology for reducing industrial CS_2 emissions.

CONCLUSIONS

Biotrickling installations can be used to treat different air streams containing reduced sulfur compounds like H_2S, mercaptans and CS_2. The biotrickling installations require only small footprints. The installations showed to be able to operate successful for several years after the start-up. For the biotrickling system operating at a viscose industry the robustness proves that the biotrickling technology is reliable for its application.

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