An evaluation of biological air treatment in combination with physical adsorption as polishing

Prevention of odor and VOC emissions at wastewater treatment facilities

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ABSTRACT

Although new advanced biotreatment sytems for odor treatment at wastewater treatment facilities have been in operation for many years as proven technology, some extra security is requested at extreme odor sensitive locations or when specific high VOCs removal (e.g. benzene) is required. An evaluation of a biological treatment system combined with adsorption as polishing is tested at two different locations and is used to illustrate the importance of a good design of the biological treatment system when combined with an activated carbon adsorption as polishing. When small molecules like hydrogen sulfide and mercaptans are removed prior to the carbon adsorption, impregnated or catalytic activated carbons are not necessary and virgin (unmodified) activated carbon can be used. Virgin activated carbon gives the advantages that (1) the capacity of organic compounds (VOCs and VOSCs) is undiminished, that (2) it contains no risk for smoldering which is associated with impregnated activated carbons and that (3) its costs per pound is much lower compared to impregnated or patented catalytic activated carbons.

Keywords: Odor treatment, Biofiltration, Zerochem, Eliminodor, Activated carbon, Polishing.

INTRODUCTION

Many cities or municipalities have to deal with odor complaints from wastewater collection and wastewater treatment facilities. A wastewater treatment plant built years ago just outside a city, is now often located near or in the middle of a new residential area. Wastewater collection systems have often been extended over the years resulting in more odor nuisance due to the septic conditions created in these extended collection systems. Cities are searching for cost efficient and community friendly methods of dealing with odors emitted from wastewater collection systems and wastewater treatment plants.

Traditionally, odor control methods for wastewater collection systems involved chemical addition to the collection system. While fairly effective, chemical addition can be very costly, can be intrusive to the local community and can give operational concerns due to changes of the daily water put-through. At these collection systems as well as at wastewater treatment facilities, odor control methods are preferred that are chemical free, relatively maintenance free, low in operational costs and operator friendly.

Although bioscrubbers and biotrickling filters for odor treatment at wastewater treatment facilities are in operation for many years at several facilities successfully as proven technology, some people want extra security when used for the first time or used at extreme odor sensitive locations. Redundancy and safety in the design of these new biological odor treatment systems is often requested to be sure that this new technology eliminates all possible odor nuisances. Physical adsorption with activated carbon as polishing step is often considered at locations that are extremely sensitive to odor nuisances. Although activated carbons have been used as proven technology for years, the use of activate carbon as polishing in combination with the new biotechnology for odor treatment at WWTP is relatively new. When to use the combination of biological treatment with adsorption as polishing? What are the benefits, the disadvantages and the risks? This paper discusses the fundamentals of biological air purification and activated carbon adsorption for odor treatment of wastewater treatment facilities. An evaluation of a combination system of biological treatment and adsorption as polishing is tested at two different locations and is used to illustrate important aspects of the design of biological treatment system combined with an activated carbon adsorption as polishing.

BIOLOGICAL ODOR TREATMENT

Fundamentals of biofiltration

Biological waste gas treatment systems can be used to remove pollutants from the air and turn into water, carbondioxide and salts. Micro-organisms, basically bacteria, are the catalyst of this process. The overall process in a biological waste gas treatment system can be divided in two phases:

- The mass transfer of the pollutants from the foul air to the biology;
- The biological degradation of the pollutants.

In the first phase, pollutants from the waste gas are absorbed in the biofilm by diffusion. In the second phase the pollutants are degraded by the bacteria present in the biofilm. The combination of different physical, chemical and biological mechanisms results in a relatively complex system. Fundamental parameters like mass transfer, absorption of the different pollutants and degradation kinetics in the biofilm, as well as airflow and water distribution are often difficult to quantify for biological waste gas purification systems. During the last couple of years, much progress has been made to understand the fundamental aspects of biological waste gas treatment system which are necessary for design and operations.

The most important aspects for design and operations are mass transfer and biological degradation kinetics. The transfer of the pollutants from the waste gas to the biofilm can be described by the following equation:

$$R = K_L a (C_g - C_g^*) \qquad (1)$$

Where:

R = the transfer velocity form the gas phase to the biofim phase (mg/h)

K_L = the mass transfer coefficient (m/h)

a = the surface area of the transfer (m^2)

C_g = the concentration of the pollutants in the gas phase (mg/m^3)
C_g^* = the concentration of the pollutants in the gas phase in equilibrium with the water phase (mg/m^3)

Henry's law predicts the concentration of the pollutants in the water phase, which is in equilibrium with the gas phase of the foul air.

$$C_w = C_g^* / H \qquad (2)$$

Where:

C_w = the concentration of the pollutants in the water phase (mg/m^3)
H = the Henry-constant

The Henry-constant is know for many pollutants, but can be used only for diluted ideal solutions. The Henry-constant can be influenced by other compounds present the biofilm, like salts or organic compounds.

Biological degradation at different concentrations can, in most situations, be described by the Monod-equation, at which the affinity of micro-organisms for the pollutants and the maximal degradation can be expressed (Figure 1).

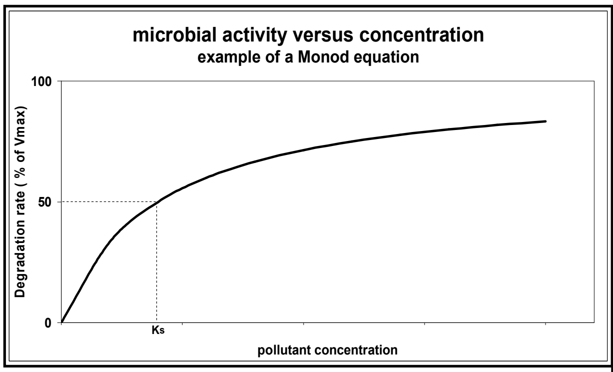
$$V = V_{max}\, C_l / (K_s + C_l) \qquad (3)$$

Where:

V = the biological degradation rate (mol/g protein/minute)
V_{max} = the maximum biological degradation rate (mol/g protein/minute)
C_l = the concentration of the pollutant in the water phase (mol/liter)
K_s = the affinity constant (is equal to the pollutant concentration at which the degradation rate is 50% of the maximum).

The microbial degradation rate is dependent on the pollutant concentrations and the affinity of a bacterium for the pollutant. At very low pollutant concentrations, the microbial activity can be relatively low.

For individual compounds, the biological treatment system is either mass transfer limited or biological reaction limited. Figure 2 illustrates the differences.



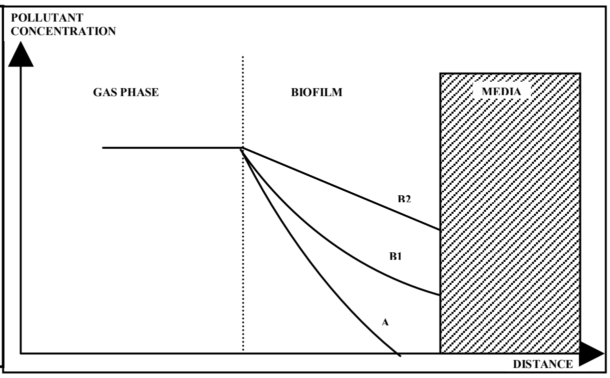


Figure 1 (left): Example of the Monod-equation showing the microbial activity is dependent on the pollutant concentration.

Figure 2 (right): Pollutant concentration in biological odor treatment system for a compound that is mass transfer limited (A) and biological reaction limited (B1 and B2). The biological reaction limited can be dependent on the pollutant concentration (zero order kinetics; B1) or independent on the pollutant concentration (first order kinetics; B2).

Recent new developments of biological odor treatment systems

Odor treatment with conventional biofilters at wastewater treatment plants had different restrictions or problems. The airstream from wastewater normally contains hydrogen sulfide (H_2S) that is degraded in a biofilter system to sulfuric acid. Sulfuric acid accumulates in the media reducing the overall odor removal efficiencies over time. Airstreams from the different sources at a WWTP are normally not completely saturated with water, which leads to partial drying out of the media especially in the inlet part of the biofilter leading to suboptimal moisture control. Problems like acidification, drying out and the requirement of media replacement at the conventional biofilters are solved by the use of multi-layer biotrickling reactors. The process control and robustness is greatly improved in these multi-layer biotrickling reactors as a more homogeneous water and air distribution and multi-layer structured synthetic media are used. These improvements result in a much lower pressure drop over the system, which makes it possible to build tall reactors, with a smaller footprint than conventional biofilters. The benefit of tall reactor shape reactors is that the footprint is much lower than a conventional biofilter. Also a higher emission point can be easily obtained to promote dispersion of the residual low concentration of odors.

Examples of biological treatment

The Hite Creek Wastewater Treatment Plant (HCWTP) in Louisville, KY is operated by the Louisville and Jefferson County Metropolitan Sewer District (MSD). As part of a major plant upgrade, several multi-layer biotrickling odor control systems (describes elsewhere by Kraakman et al., 2001 and 2005) were installed to treat odorous air from various processes at the facility. The odor removal requirements, as required and defined by Bowker & Associates Inc. and Webster Environmental Inc., were H_2S removal $> 99\%$ or outlet ≤ 0.5 ppmv and odor removal $> 95\%$ or ≤ 75 D/T if inlet < 1000 D/T.

The removal efficiencies were continuously monitored using a calibrated Interscan Model 1176 H_2S analyzer with a dual range of 0 – 10 ppmv by 0.1 ppmv and 0 – 100 ppmv by 1 ppmv (inlet concentration hydrogen sulfide). Outlet H_2S concentration was measured using a factory-calibrated Arizona Instruments Jerome 631-X H_2S analyzer, with a range of 0.002 ppmv to 50 ppmv. A minimum of two inlet samples and two outlet samples were collected in 10 liter Tedlar bags using teflon tubing and an SKC vacuum chamber. Inlet and outlet samples were collected simultaneously using identical sampling trains. Bag samples were shipped by overnight carrier to St. Croix Sensory in Lake Elmo, MN for determination of odor concentration in accordance with ASTM E-679-91. The analysis used the IITRI olfactometer at a panelist presentation rate of 0.5 l/min. Simultaneously during collection of samples for odor panel analysis, a minimum of two inlet and two outlet samples were collected from each unit in 3 liter Tedlar bags using the SKC vacuum chambers. Samples were shipped by overnight carrier to Mayfly Laboratories in Mystic, CT for determination of reduced sulfur compounds via gas chromatograph with flame photometric detector (GC-FPD).

The testing of the biological odor control systems shows that for all biological odor treatment units the removal efficiencies of odor and total reduced organic sulfur compounds are approximately 95%. Data of two of these biological odor treatment units are shown in Table 1 of Appendix 1.

ODOR TREATMENT USING CARBON ADSORPTION

Introduction

A biological odor treatment can be very efficient treating odor emissions from the different sources at a wastewater treatment plant. The example of a multi-layer biotrickling odor treatment system at a municipal wastewater treatment facility shows odor removal efficiencies around 95% at the wastewater inlet of the wastewater treatment plants (headworks) and at the sludge treatment of a wastewater treatment plant (sludge holding tanks).

Biological odor treatment followed by carbon polishing might be of benefit in situations where the location is extreme sensitive to odor nuisance and odor removal efficiency is required higher than 95%. Especially pump stations at wastewater collection systems that are located in residential areas are sensitive. Another benefit of carbon polishing is where, besides legislation to eliminate odor nuisance, additional regulations for specific compounds are present. For example, in California some locations require additional high removal of specific VOCs like benzene. Biological odor treatment followed by carbon polishing might be of benefit in this situation. To remove the residual low pollutant concentrations, a biological system might need to be expanded as the volumetric removal capacity and removal efficiency are often directly dependent on the pollutant concentration at low concentrations as shown previously. The combination of biological treatment with carbon polishing might than be helpful in those situations where insufficient footprint is available for expanding biological treatment to reduce required low outlet concentrations.

Odor removal with activated carbon adsorption is a very good possibility as it often has been used successfully as stand alone units.

Fundamentals of carbon adsorption

The surface of a solid always accumulates a concentration of molecules from gaseous or liquid environment, a process called adsorption. The surface area is therefore important for the removal capacity of an adsorbent. For the treatment of air streams with relative low pollutant concentrations, granular activated carbon (GAC) is mostly used. The adsorption capacity of individual pollutants can be summarized by the empirically determined Freundlich isotherm.

$$X/M = k\,c^{1/n} \qquad (4)$$

X/M = the weight of the adsorbed pollutant per weight adsorbent (g/100 g)
Where:
c = the concentration of the pollutant in the gas phase (ppmv)
k = constant
$1/n$ = constant

The adsorption capacity of an activated carbon depends strongly on the characteristics of the pollutants to be removed. Due to the hydrophilic character of the activated carbon, large, nonpolar molecules are better adsorbed than smaller, polar compounds. Factors like temperature, relative humidity of the waste gas and clogging due to dust also influences the overall adsorption capacity of the activated carbon. The carbon life can be calculated based on the adsorption of the target pollutants. However, since odorous air is usually a complex mixture of unknown pollutants that influence each others adsorption capacity, pilot testing is normally recommended to determine carbon life based on odor breakthrough.

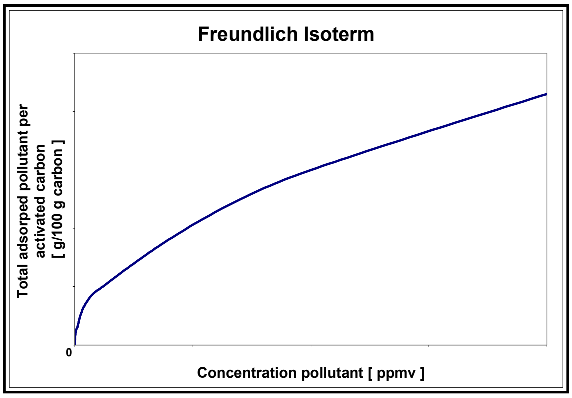


Figure 3: Freundlich adsorption isotherm showing the relation between the pollutant concentration and the total adsorption capacity of an activated carbon.

There are different kinds of activated carbons which can be divided in virgin, impregnated, and catalytic (WEF, 2004). Virgin activated carbon adsorbs volatile organic compounds very well, but adsorbs relative small inorganic molecules like ammonia and hydrogen sulfide poorly. For the removal of odorous compounds at wastewater treatment facilities virgin activated carbon is hardly used due to the relative high hydrogen sulfide concentrations.

Impregnated activated carbon is a virgin activated carbon impregnated with sodium hydroxide (NaOH), potassium hydroxide (KOH) or potassium iodide (KI) to stimulate the chemical reaction with acid pollutants like hydrogen sulfide or methyl mercaptan. The impregnate reduces the adsorption capacity of other volatile organic compounds as it blocks some of the adsorption pores. Regeneration of the adsorption capacity of the acid pollutants is theoretically possible by washing with the impregnate. The regeneration of the adsorption capacity of other pollutants like the volatile organic compounds is not possible by washing. Thermal regeneration is also not possible as the impregnate and sulfide in the spent activated carbon influence thermal regeneration negatively. Impregnated activated carbon has also the disadvantage that it undergoes an exothermic reaction in the presence of oxygen that can heat the carbon and cause smoldering or spontaneous combustion when insufficient cooling air flows through the carbon to remove the heat. To reduce the risk of smoldering or fire activated carbon filters with impregnated activated carbon should be design with extra precautions like fire suppression systems or sealed dampers, which isolate the bed if the fan shuts off.

Catalytic activated carbon is an activated carbon with enhanced catalytic activity. The catalytic site on the carbon (mostly metal ions) stimulates the oxidation of hydrogen sulfide. Hydrogen sulfide is then chemically oxidized to elemental sulfur and sometimes to sulfuric acid. When hydrogen sulfide is completely oxidized to sulfuric acid, the catalytic carbon can be regenerated for hydrogen sulfide adsorption with water. Special safety requirements are required since the wash water can be extremely acid.

Table 2: Physical characteristics of different activated carbons.

Property	**Virgin activated carbon**	**Impregnated activated carbon**	**Catalytic activated carbon**
Adsorption capacity (gr H_2S/cc carbon)[a]	app. 0.02	app. 0.13	app. 0.09
Ignition temperature	380 - 425°C	200 - 225°C	380 – 425°C
Regeneration method	Thermal	NaOH of KOH (usually not done onsite as soaking takes days)	Water (can be done onsite/ large water amount required)
Disposal	Landfill (might be considered as hazardous waste) or Thermal reactivation (only at large quantities)	Landfill (might be considered as hazardous waste)	Landfill (most likely considered as hazardous waste) or Thermal reactivation (only at large quantities and low in elemental sulfur)

[a] based on test method TM-41.

Unlike impregnated carbon, that contains in general impregnates of a very high pH, virgin and catalytic activated carbons are safe to handle and not classified as hazardous. Virgin activated carbon may even still be considered as nonhazardous after breakthrough of odors.

ODOR TREATMENT WITH THE COMBINATION OF BIOLOGICAL TREATMENT AND CARBON POLISHING

Introduction

The example of the improved biological treatment systems shows that high odor removal efficiencies are possible. But high odor removal efficiencies (>95 %) might not be good enough in some applications, especially sensitive locations like pump stations in wastewater collection systems. Polishing with activated carbon reduces the risk of odor nuisance at these locations.

The drawback of activated carbon filters as stand alone systems is the requirement of frequent carbon change-out. Also, the unpredictability of the time required before changing out the carbon might be a drawback, as the carbon life for odor removal is difficult to predict. Impregnated activated carbon is mostly used to prevent breakthrough of H_2S. Besides the breakthrough of H_2S the breakthrough of reduced organic sulfur compounds is often mentioned as the cause for the odor breakthrough. A biological treatment prior to the carbon as polishing can effectively remove H_2S and most of all VOC present to address these drawbacks of activated carbon filters.

When small molecules like hydrogen sulfide are removed prior to the carbon adsorption, impregnated or catalytic activated carbons are not necessary and virgin (unmodified) activated carbon can be used. Virgin activated carbon gives the advantages that (1) the capacity of organic compounds (VOCs and VOSCs) are undiminished, that (2) it contains no risk for smoldering which is associated with impregnated activated carbons and that (3) its costs per pound is much lower when compared to impregnated or patented catalytic activated carbons.

The advantages and disadvantages of the combination of biological treatment with carbon polishing

Biological odor treatment followed by carbon polishing might be of benefit in situations where the location is extremely sensitive to odor nuisance and very high odor removal efficiencies are required. Especially pump stations in wastewater collection systems that are located in residential areas are sensitive. Table 3 summarizes the most important advantages of the combination of biological treatment with carbon polishing.

Table 3: The advantages and disadvantages of biological treatment, carbon adsorption and the combination of biological treatment with carbon polishing for odor treatment at wastewater treatment facilities.

	Advantages	Disadvantages
Biological treatment	- Low investment costs; - Easy to operate; - Low maintenance cost; - No media replacement (only bioscrubber/trickling filters); - No waste generation (green technology); - Removal high of H_2S concentrations very possible (with advanced bioscrubber/trickling filters).	- Requires larger footprint (especially conventional biofilters). - Removal of certain (poor water soluble, difficult biodegradable) VOC require large systems; - Proper design required (to obtain high removals and robustness).
Carbon adsorption	- Low investment costs; - Easy to operate; - Small footprint.	- Not effective for the removal of small and hydrophylic compounds; - Impregnated or catalytic activated carbon required; - Hazardous for handling and possible

		smoldering (impregnated activated carbon is used); - Generation of waste (spent carbon); - Operational cost for frequent carbon replacements;
Combination of biological treatment with carbon polishing	- Virgin activated carbon can be used as it lower costs for carbon; - Very effective in the removal of a wide range of compounds; - Removal of high H_2S concentrations very good possible (with advanced bioscrubber/trickling filters); - Very effective at sensitive locations; - Generation of less waste which will also probably less hazardous (compared with stand alone carbon filter); - Low maintenance cost; - Easy to operate;	- Higher investment costs possible; - Design more complicated.

The combination of biological treatment with carbon polishing might be helpful in those situations where insufficient footprint is available for expanding biological treatment to reduce to required low outlet concentrations.

The use of biological treatment prior to a carbon polishing makes it possible to use virgin activated carbon. The biological treatment has to remove small hydrophilic pollutants like hydrogen sulfide, ammonia and mercaptans that are normally difficult to remove with virgin activated carbon. An advanced biological treatment system should be very good capable when designed properly.

The advantages of the use of virgin (unmodified) activated carbon over impregnated or catalytic activated carbons are:

1) The adsorption capacity of organic compound (VOCs and VOSCs) are undiminished;
2) The adsorption capacity of organic compounds will not be reduced by salts as the deposition of inorganic salts is neglect able when compared to impregnated of catalytic activated carbons;
3) The costs are significantly lower than these of impregnated carbons of patented catalytic activated carbons;
4) The density of the activated carbon is in general lower;
5) Virgin carbon does not undergo an exothermic reaction in the presence of oxygen that can heat the carbon and cause smoldering or even combustion (like impregnated carbons) when insufficient air flow through the carbon filter.

Activated carbon is especially very effective as polishing as the removal efficiency is not dependent on the low pollutant concentration in the air as shown earlier.

Examples of a combination of biological treatment with carbon polishing at different locations

A combination of biological treatment with carbon polishing is tested at two different locations. At one location (Location A) foul air from the primary effluent line at a wastewater treatment facility treating municipal and industrial wastewater is treated; Hyperion WWTP, Los Angeles, California. The other location (Location B) treats foul air from the headworks from a wastewater treatment facility treating mostly municipal wastewater only; Houten WWTP, Utrecht, The Netherlands.

A prototype unit contained the combination of biological treatment with carbon polishing in one system. The system as shown in Figure 4 had a 7 feet diameter and a height of 8 feet. The biological filter utilizes a synthetic plastic media that is expected not to be replaced at all. The unit can be disassembled to replace the carbon cartridge as needed. The odorous air is first treated biologically, than passes through a mist eliminator before entering the carbon polisher.

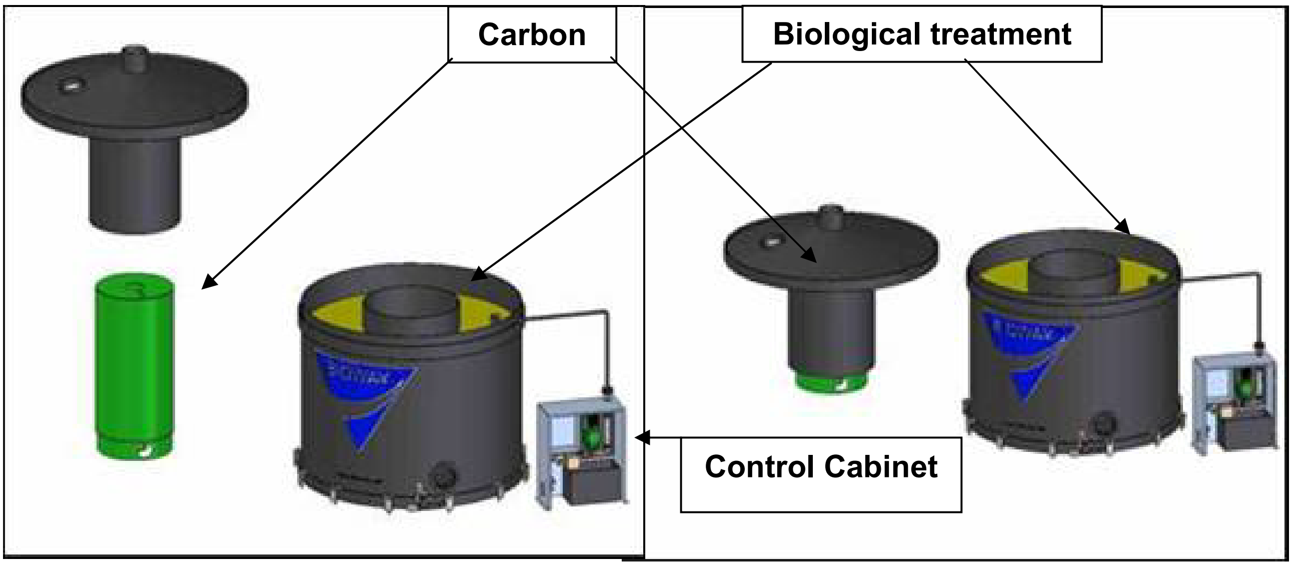


Figure 4: The prototype combination unit of biological treatment with carbon polishing.

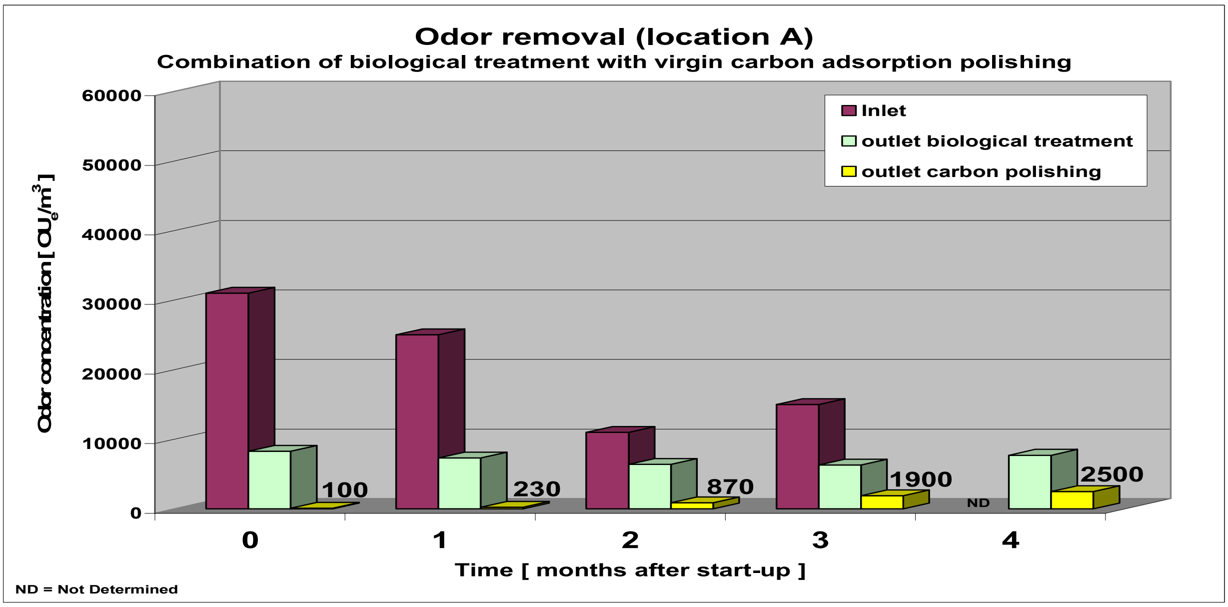
The removal efficiencies were continuously monitored using a calibrated Interscan Model 1176 H_2S analyzer with a dual range of 0 – 10 ppmv by 0.1 ppmv and 0 – 100 ppmv by 1 ppmv (inlet concentration hydrogen sulfide) or a Odalog H_2S datalogger with a range of 0 – 1000 ppm or 0 – 50 ppmv. Outlet H_2S concentration was measured using a factory-calibrated Arizona Instruments Jerome 631-X H_2S analyzer, with a range of 0.002 ppmv to 50 ppmv or a Odalog H_2S datalogger with a range of 0 – 50 ppmv or 0 2 ppmv. Inlet samples and outlet samples were collected in Tedlar bags. Bag samples were shipped by overnight carrier to St. Croix Sensory in Lake Elmo, MN, USA or to Odournet, Amsterdam, The Netherlands for determination of odor concentration in accordance with international standard EN13725. The analysis used the olfactometer at a panelist presentation rate of 20 l/min. Frequently, simultaneously during collection of samples for odor panel analysis, inlet and outlet samples were collected in Tedlar bags for the analyses of reduced sulfur compounds. Samples were shipped by overnight carrier to Mayfly Laboratories in Mystic, CT, USA or to the Radboud University, Nijmegen, The Netherlands for determination via gas chromatograph with flame photometric detector (GC-FPD).

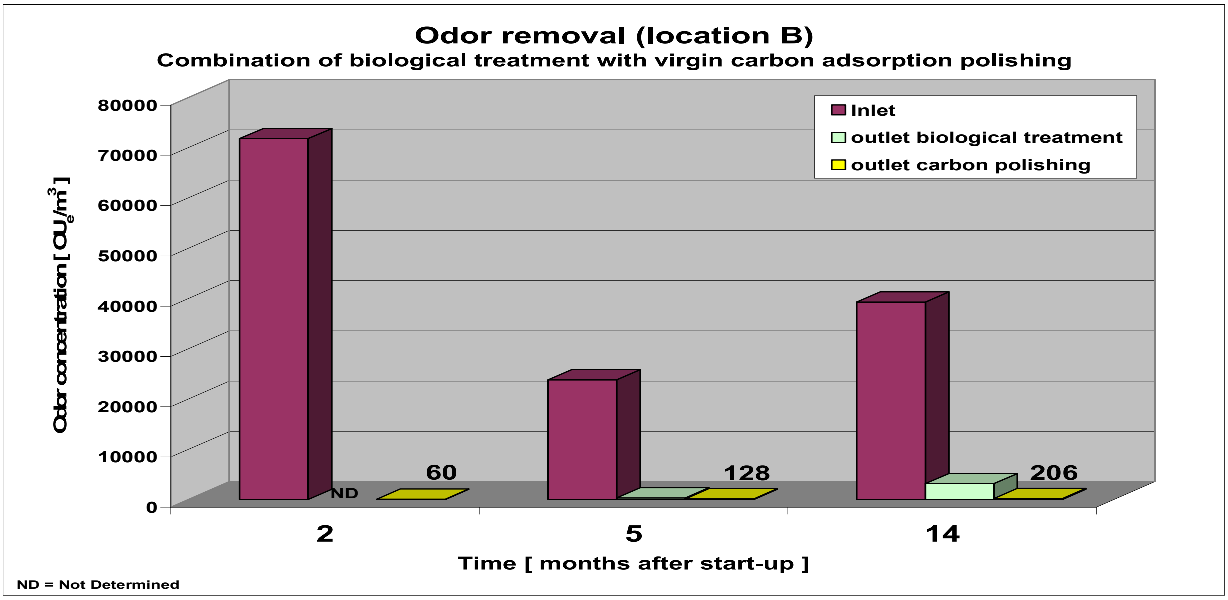
Table 4 shows a summary of the operations of the system at both locations. The odor treatment system is designed for an airflow up to 600 cfm and inlet H_2S-concentratins up to 50 ppmv at 600 cfm. At both locations the same system is operated. At location A, a lower inlet airflow, a lower inlet odor concentrations and a higher temperature were present, when compared to location B. Based on these conditions, the conditions at location A should normally benefit to a lower residual outlet odor concentration from the carbon polisher.

Table 4: A summary of the operations conditions of the combination system of biological treatment with carbon polishing at tested location.

		Location A	**Location B**
Location		MWTP treating municipal and industrial wastewater; Los Angeles, USA	MWTP treating mostly municipal wastewater; Houten, The Netherlands
Odor treatment system		prototype Eliminodor ™	prototype Eliminodor ™
Airflow	cfm	450	600
Air temperature	°C	app. 15-35	app. 5-30
Inlet odor-concentration	OU_e/m^3	app. 10,000-30,000	app. 20,000-80,000

Figure 5a and Figure 5b show odor removal over time in the combination system of biological treatment with carbon polishing in location A and location B respectively. Figure 6 and Figure 7 show respectively the overall odor removal efficiency and the outlet odor concentrations. The overall odor removal of this system showed to be very high. At both locations the overall odor removal efficiency exceeded 99.5% shortly after the start-up. Although the carbon polishing at location B kept removing the odors for a period of more than a year, the carbon polishing at location A experienced a drop in efficiency already after approximately 2 months.





Figures 5a and b: The odor removal over time in the combination system of biological treatment with carbon polishing at respectively location A and location B.

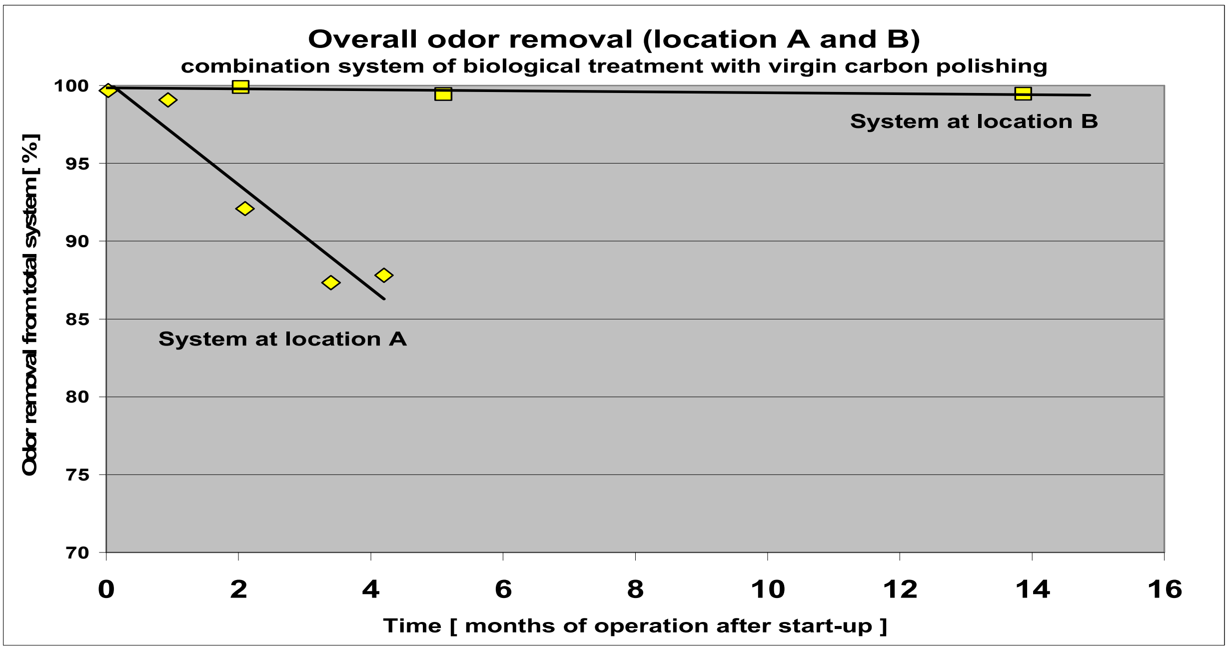


Figure 6: The odor removal efficiency over time in the combination system of biological treatment with carbon polishing at respectively location A and location B.

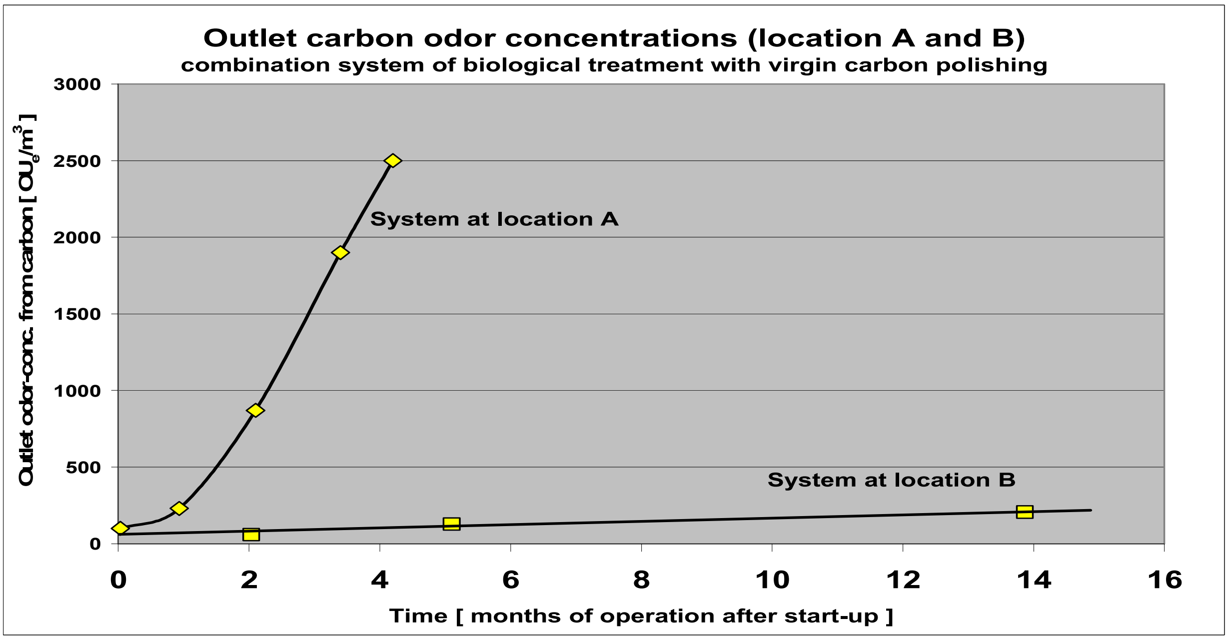


Figure 7: The outlet odor concentration over time in the combination system of biological treatment with carbon polishing at respectively location A and location B.

Both systems started out with outlet odor concentrations around 100 D/T as measured according to the standard method EN13725. Although the inlet odor concentration were in general lower at location A, the inlet H_2S-concentration and the total inlet reduced organic sulfur compounds were higher at location A. Table 5 illustrates that the H_2S-concentration and the total inlet reduced organic sulfur compounds entering the carbon polisher at location A were also much higher than at location B.

Table 5: A summary of the removal effciencies of the combination system of biological treatment with carbon polishing at tested location.

		Location A	**Location B**
Location		MWTP treating municipal and industrial wastewater; Los Angeles, USA	MWTP treating mostly municipal wastewater; Houten, The Netherlands
Airflow	cfm	450	600
Inlet system: Odor-concentrations	OU$_e$/m^3	app. 10,000-30,000	app. 20,000-80,000
H2S-concentrations	ppmv	**app. 0-200 ppmv**$^{1)}$	**app. 0-60 ppmv**$^{3)}$
VOSCs-concentrations	ppbv	**app. 1,500**$^{2)}$	**app. 100-500**$^{3)}$

Inlet carbon polishing:			
Odor-concentrations	OU_e/m^3	app. 6,000- 8,500	app. 300- 3,500
H2S-concentrations	ppmv	**app. 0- 10 ppmv**[1]	**app. 0- 2 ppmv**[3]
VOSCs-concentrations	ppbv	**app. 1,200**[2]	**app. 40- 60**[3]
Outlet carbon polishing:			
Odor-concentrations	OU_e/m^3	app. 100- 2,500	app. 60- 250
H2S-concentrations	ppmv	**app. 0 – 0.9**[1]	**app. < 0.2**[3]
VOSCs-concentrations	ppbv	**app. 500**[2]	**app. 15- 40**[3]

[1] See data of measurements Table 6-A in Appendix 2.
[2] See data of measurements Table 6-B in Appendix 2.
[3] See data of measurements Table 7 in Appendix 2.

DISCUSSION

Biological systems for odor treatment are in general operated at relatively low volumetric removal capacities. Especially odorous foul air from wastewater systems contains in general a mixture of different compounds with concentrations in the ppbv or ppmv range. High inlet concentrations accelerate the mass-transfer and normally also the biological activity in biofiltration systems. High inlet concentrations increase the mass-transfer from the gas phase (foul air) to the water phase (biofilm layer) as shown by the Henry-coefficient. Higher inlet concentrations increase in general the biological activity as shown by the Monod-equation especially in the low concentration range. The removal efficiency in a biological system treating the airflow of X cfm with a concentration of Y ppmv is in general higher than treating the airflow of 2X cfm with a concentration of ½Y ppmv, especially at low concentrations.

Unlike biofiltration systems, the removal efficiency of carbon adsorption at the relatively low concentrations is not affected by the inlet concentration. The removal capacity of a carbon filter treating the airflow of X cfm with a concentration of Y ppmv is in general the same as treating the airflow of 2X cfm with ½Y ppmv as long as the contact time does not get too low. So when extremely low outlet concentrations are required, the removal capacity of the carbon adsorption is not really dependent on the inlet foul air concentration of a pollutant.

Figure 5a and b and Figure 6 and 7 show that the carbon polisher can lose its efficiency already after several months. The overall removal efficiency of the combination system tested using biological treatment with a carbon polisher reduces at location A from more than 99% to approximately 85% in approximately 4 to 5 months. Despite the fact that the airflow was lower through the system at location A (450 cfm versus 600 cfm at location B), the concentrations of pollutants entering the carbon polishing seem to be too high. Apparently to obtain long carbon life H_2S-concentration and the total reduced organic sulfur compounds entering the carbon polishing should be low enough.

If the combination of biological treatment and carbon polishing is considered or required, good engineering of the whole system is important. When virgin activated carbon is used in the carbon polishing and H_2S and important odorous compounds like the relatively small organic reduced sulfur compounds are not sufficiently removed in the biological system, the carbon life is most likely very minimal (only months).

In order to prolong the life of the activated carbon media, air dryers are sometimes used on foul air streams. All free water after the biological treatment has to be removed to prevent problems with carbon adsorption. Therefore a fan is normally placed between the biological system and the activated carbon filter to increase the air temperature a little and reduce the relative humidity of the air. The combination system tested – operated without any air dryer and the fan between the biological treatment and the carbon adsorption- did not show any difficulties with the high relative humidity of the air entering the activated carbon. Visual inspection of samples taken from the carbon after months of operation did not show high moisture contents in the carbon.

The addition of a carbon filter behind a biological treatment system is often seen at very sensitive locations to reduce the risk for insufficient odor removal. Full-scale conventional biological air treatment systems have often given failures due to poor design or lack of maintenance. Scepsis of biofiltration is sometimes the result, especially at sensitive locations where big investments are made for rural development. Even now that biological air purification technology has developed greatly over the last couple of years as different full-scale projects have shown great improvement, especially on operational robustness and operational costs, carbon filter are used as security.

For design of odor treatment the starting points should be that the total costs (investment and operational) are low and that the system is robust and operator friendly. The combination of biological treatment followed by carbon polishing introduces the risk that the overall system is designed too small and that carbon polishing is more that only polishing. The size of the biological treatment system might be reduced to save on investment costs. A reduced biological treatment system will mostly directly lead to an increase of operational costs as carbon has to be exchanged more frequently. The trade off between the investment costs of the biological treatment system and the operation costs for change out of the carbon is difficult to make. Important to know is what kind of compounds will cause the breakthrough of activated carbon. These compounds should be treated in the biological treatment system optimal. Examples illustrate (Norit, 1999) that the odor breakthrough at wastewater treatment facilities is in general caused by reduced sulfur compounds of which hydrogen sulfide and the reduced organic sulfur compounds methyl mercaptan, dimethylsulfide, dimethyldisulfide, carbonylsulfide are likely the most important ones. Biological treatment of these compounds to levels that are as low as possible will reduce frequency of activated carbon change-out at wastewater treatment facilities greatly. All will lead to a lower present worth value of the combined biological with carbon polishing odor treatment system.

CONCLUSIONS

A biological odor treatment can be very efficient in treating odor emissions from different sources of a wastewater treatment facility. Examples of a biological odor treatment system at a municipal wastewater treatment facility show odor removal efficiencies around 95% at the wastewater inlet of the plants (headworks) and sludge treatment (sludge holding tanks).

Biological odor treatment followed by carbon polishing might be of benefit in situations where the location is extremely sensitive to odor nuisance and extremely high odor removal efficiency are required. Especially pump stations at wastewater collection systems that are located in residential areas are sensitive. Another benefit of carbon polishing is where additional regulations for specific compounds are present. For example, in California some locations require additional high removal of specific VOCs like benzene. Biological odor treatment followed by carbon polishing might in this situation of benefit. To remove the residual low pollutant concentrations, a biological system might need to be expanded as the volumetric removal capacity and removal efficiency are often directly dependent on the pollutant concentration at low concentrations. The combination of biological treatment with carbon polishing is in those situations helpful where insufficient footprint is available for expanding biological treatment to reduce required low outlet concentrations.

When small molecules like hydrogen sulfide are removed prior to the carbon adsorption, impregnated or catalytic activated carbons are not necessary and virgin (unmodified) activated carbon can be used. Virgin activated carbon gives the advantages that (1) the capacity of organic compound (VOCs and VOSCs) are undiminished, that (2) it contains no risk for smoldering which is associated with impregnated activated carbons and that (3) its costs per pound is much lower when compared to impregnated or patented catalytic activated carbons.

If the combination of biological treatment and carbon polishing is considered or required good engineering of the whole system is important. When virgin activated carbon is used in the carbon polishing and H_2S and important odorous compounds like the relatively small organic reduced sulfur compounds are not sufficiently removed in the biological system, the carbon life is most likely very minimal (only months).

The adsorption breakthrough of activated carbon bed is in most likely in most causes caused by reduced sulfur compounds of which hydrogen sulfide and the reduced organic sulfur compounds methyl mercaptan, dimethylsulfide, dimethyldisulfide, carbonylsulfide are likely most important. Removal of these compounds in the biological treatment system to as low as possible levels will reduce frequency of activated carbon change-out at wastewater treatment facilities greatly. All will most likely lead to a lower present worth value of the combined biological with carbon polishing odor treatment system.

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APPENDIX 1

Table 1: The removal efficiencies of stand alone biological treatment systems treating odor emissions from a municipal wastewater treatment plant.

Influent Pump Station
Biological Odor Control System #1 (Zerochem 2200-1) operated at 830 cfm, August 2, 2005

	Time AM	Odor Conc. D/T	Reduced Sulfur Compounds,[1] ppb								
			H_2S [3] (lab)	COS	MM	DMS	CS_2	1(m)(E) 1-P	AMS	DMDS	DMTS
Inlet	8:30	**4,600**	**25,091**	55	16.8	7.4	58	<3	1.9	1.8	0.8
Outlet	8:30	**24**	**8**	17	<3	0.4	33	<3	<3	<3	<3
Inlet	9:30	**7,000**	**38,881**	73	5.7	9.6	59	<3	<3	33	0.3
Outlet	9:30	**40**	**26**	34	<3	<3	18	<3	<3	0.8	<3
Inlet	10:30	**7,000**	**21,424**	17	3.4	0.9	18	<3	<3	17	<3
Outlet	10:30	**19**	**14**	8	<3	<3	12	<3	<3	<3	<3

Sludge Holding Tanks
Biological Odor Control System #3 (Zerochem 2200-2) operated at 920 cfm, August 3, 2005

	Time AM	Odor Conc. D/T	Reduced Sulfur Compounds,[1] ppb								
			H_2S [4] (lab)	COS	MM	DMS	CS_2	1(m)(E) 1-P	AMS	DMDS	DMTS
Inlet	9:00	**1,900**	**512[2]**	6.8[2]	0.1[2]	0.9[2]	8.1[2]	<3[2]	<3[2]	0.4[2]	<3[2]
Outlet	9:00	**16**	**5.9**	7.5	2.6	19.7	7.8	<3	<3	<3	<3
Inlet	10:10	**1,500**	**5,184**	7.5	0.1	4.8	19	<3	<3	0.1	<3
Outlet	10:10	**330**	**5.9**	14	3.8	78	11	1.3	3.4	119	0.2
Inlet	10:30	**1,800**	**2,756**	20	10.9	146	16	<3	8.4	23	0.8
Outlet	10:30	**530**	**8.4**	9.5	7.6	118	11	<3	7.9	22	0.3
Inlet	11:30	**1,800**	**3,377**	17	21	106	12	<3	<3	2.3	<3
Outlet	11:30	**27**	**5.9**	19	3.3	102	14	<3	<3	1.9	<3

1) H_2S = hydrogen sulfide, COS = carbonyl sulfide, MM = methyl mercaptan (methanethiol), DMS = dimethyl sulfide, CS_2 = carbon disulfide, 1(m)(E)1-P = 1-(methylthio)(E)1-propene, AMS = allyl methyl sulfide, DMDS = dimethyl disulfide, DMTS = dimethyl trisulfide.

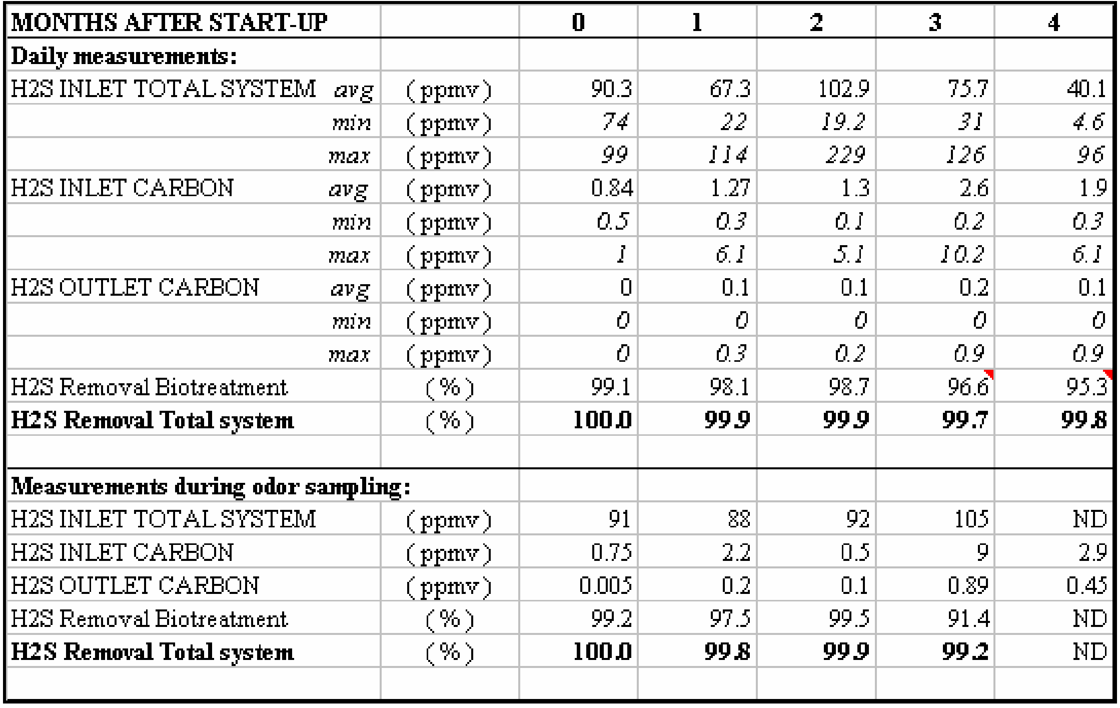
2) These data are considered invalid due to a damaged or defective sample bag.

3) The inlet H_2S concentration as measured with the H_2S-meters at unit #1during odor testing ranged from 2.7 to 96 ppmv, and averaged 25.4 ppmv. Outlet levels ranged from 0.003 to 0.028 ppmv and averaged 0.011 ppmv. Instantaneous H_2S removal efficiency ranged from 99.70 to 99.97 percent. The mean removal efficiency was 99.9 percent.

4) Unit #3 was designed for an average H_2S of 2 ppmv and a peak of 5 ppmv. On August 1, inlet H_2S - as measured with H_2S-meters - was measured at 15 ppmv at 2:50 PM. On August 2, after MSD operations staff turned off the air for approximately 6 hours to decant the supernatant and then turned the air back on, H_2S levels to the biological odor treatment system #3 exceeded 100 ppmv. Later in the afternoon it showed inlet H_2S levels of over 15 ppmv after shutting off the air for about 1½ hours and restarting the blower. During the next morning H_2S and odor test showed that the inlet H_2S ranged from 4.4 to 8.8 ppm, and averaged 5.9 ppm. Outlet H_2S ranged from 0.005 to 0.28 ppm and averaged 0.052 ppm. Average H_2S removal efficiency was 99.1 percent.

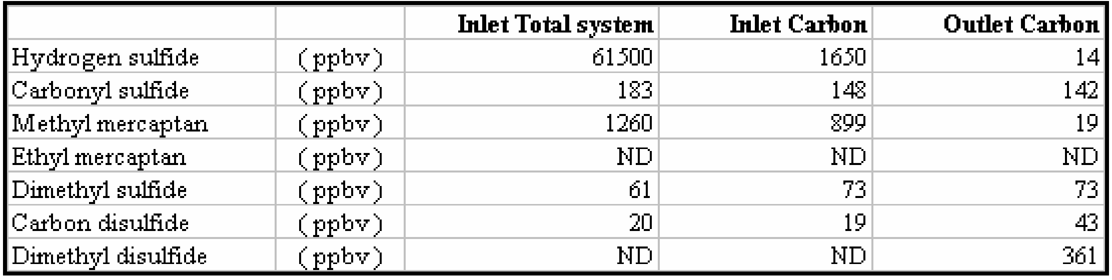
APPENDIX 2

Table 6-a: The H2S-removal of the system over time at location A.



MONTHS AFTER START-UP		**0**	**1**	**2**	**3**	**4**
Daily measurements:						
H2S INLET TOTAL SYSTEM *avg*	(ppmv)	90.3	67.3	102.9	75.7	40.1
min	(ppmv)	*74*	*22*	*19.2*	*31*	*4.6*
max	(ppmv)	*99*	*114*	*229*	*126*	*96*
H2S INLET CARBON *avg*	(ppmv)	0.84	1.27	1.3	2.6	1.9
min	(ppmv)	*0.5*	*0.3*	*0.1*	*0.2*	*0.3*
max	(ppmv)	*1*	*6.1*	*5.1*	*10.2*	*6.1*
H2S OUTLET CARBON *avg*	(ppmv)	0	0.1	0.1	0.2	0.1
min	(ppmv)	*0*	*0*	*0*	*0*	*0*
max	(ppmv)	*0*	*0.3*	*0.2*	*0.9*	*0.9*
H2S Removal Biotreatment	(%)	99.1	98.1	98.7	96.6	95.3
H2S Removal Total system	(%)	**100.0**	**99.9**	**99.9**	**99.7**	**99.8**
Measurements during odor sampling:						
H2S INLET TOTAL SYSTEM	(ppmv)	91	88	92	105	ND
H2S INLET CARBON	(ppmv)	0.75	2.2	0.5	9	2.9
H2S OUTLET CARBON	(ppmv)	0.005	0.2	0.1	0.89	0.45
H2S Removal Biotreatment	(%)	99.2	97.5	99.5	91.4	ND
H2S Removal Total system	(%)	**100.0**	**99.8**	**99.9**	**99.2**	ND

Table 6-b: The removal of reduced sulfur compounds in the system at location A after 14 weeks of operation after the start-up.



		Inlet Total system	**Inlet Carbon**	**Outlet Carbon**
Hydrogen sulfide	(ppbv)	61500	1650	14
Carbonyl sulfide	(ppbv)	183	148	142
Methyl mercaptan	(ppbv)	1260	899	19
Ethyl mercaptan	(ppbv)	ND	ND	ND
Dimethyl sulfide	(ppbv)	61	73	73
Carbon disulfide	(ppbv)	20	19	43
Dimethyl disulfide	(ppbv)	ND	ND	361

Table 7: The removal of reduced sulfur compounds in the system at location B.

		Inlet Total system	**Inlet Carbon**	**Outlet Carbon**
Measurement during odor sampling after 2 months of operation:				
Hydrogen sulfide	(ppbv)	9000	ND[1]	<4
Carbonyl sulfide	(ppbv)	15	ND[1]	5
Methyl mercaptan	(ppbv)	380	ND[1]	<4
Dimethyl sulfide	(ppbv)	20	ND[1]	14
Carbon disulfide	(ppbv)	<3	ND[1]	<3
Dimethyl disulfide	(ppbv)	17	ND[1]	<4
Dimethyl trisulfide	(ppbv)	8	ND[1]	<5
Measurement during odor sampling after 5 months of operation:				
Hydrogen sulfide	(ppbv)	ND[1]	ND[1]	ND[1]
Carbonyl sulfide	(ppbv)	<3	<3	<3
Methyl mercaptan	(ppbv)	160	13	<4
Dimethyl sulfide	(ppbv)	15	7	4
Carbon disulfide	(ppbv)	<3	<3	<3
Dimethyl disulfide	(ppbv)	10	3	7
Dimethyl trisulfide	(ppbv)	5	<5	<5
Measurement during odor sampling after 14 months of operation:				
Hydrogen sulfide	(ppbv)	3800	33	< 3
Carbonyl sulfide	(ppbv)	6	3	4
Methyl mercaptan	(ppbv)	106	24	< 4
Dimethyl sulfide	(ppbv)	11	7	9
Carbon disulfide	(ppbv)	< 3	< 3	< 3
Dimethyl disulfide	(ppbv)	8	8	22
Dimethyl trisulfide	(ppbv)	<5	<5	<5

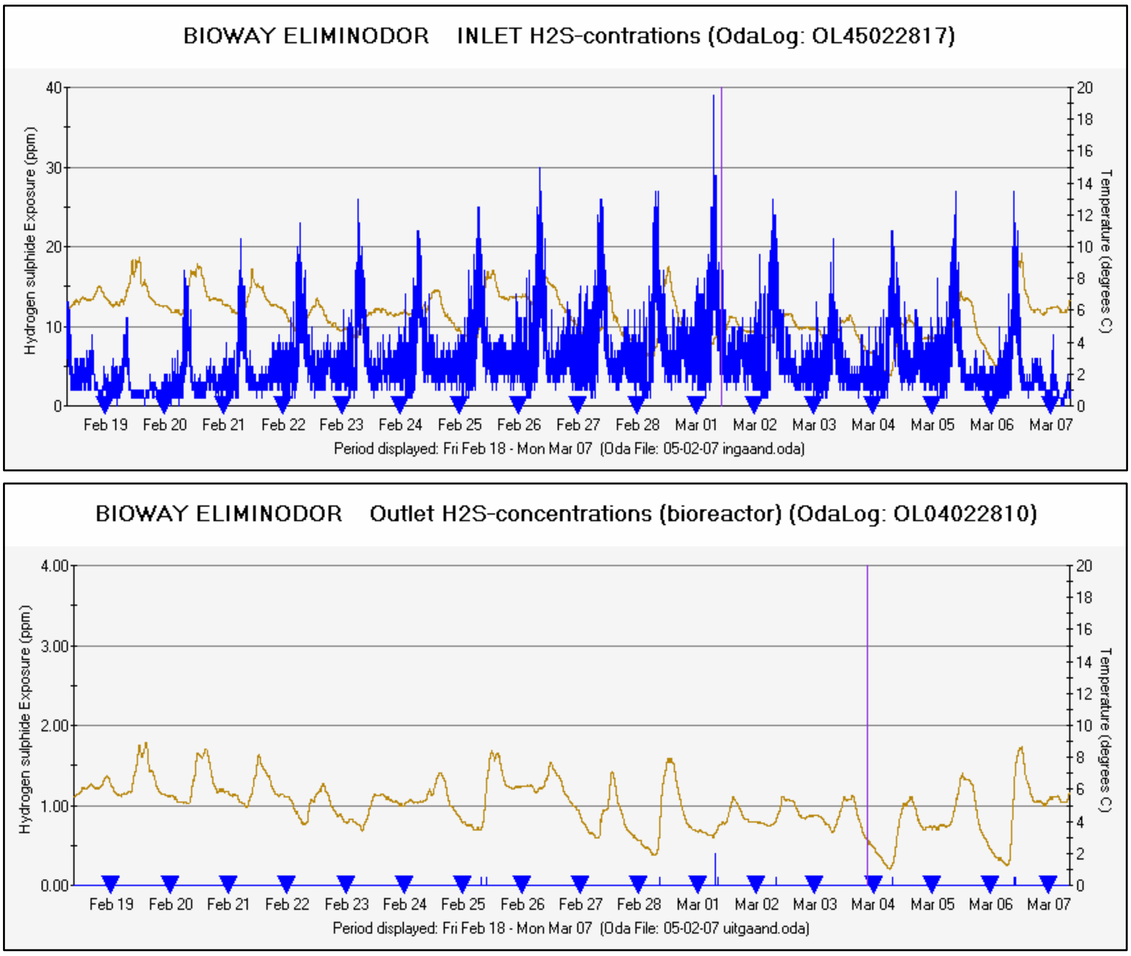


Figure 8-a and 8-b: The inlet H2S-concentrations (Figure 8-a) and the outlet H2S-concentration (Figure 8-b) from the biotreatment (bioreactor) at the system at location B after 7 months of operation.