A COMPARISON OF AN ORGANIC BIOFILTER AND AN INORGANIC BIOFILTER FOR THE TREATMENT OF RESIDUAL ODORS EMANATING FROM A BIOSOLIDS DE-WATERING FACILITY

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ABSTRACT

The following paper is a comparison of an organic media biofilter and a synthetic media biofilter for the treatment of residual odors emanating from the operation of a biosolids dewatering and truck loading system at the City of Toronto's Ashbridges Bay Treatment Plant.

The system compared was an in-ground, header/lateral system operated in a forced draft, up flow, open top configuration. The biofilter system consists of a 72,000 m^3/hr four cell arrangement, consisting of a pre-humidification system, supplementary moisture addition through a surface irrigation system and variable frequency controlled ventilation fans. The odor control system was constructed with a chemical scrubber system using sodium hypochlorite and sodium hydroxide, followed by the biofilter. Odor testing revealed that the biofilter was sufficient to treat the odors without pre-treatment from the scrubber system. The scrubber system was removed from operation, and the biofilter maintained its exceptional performance. The scrubbers have yet to be re-commissioned.

Biosolids dewatering facilities are typically characterized by persistent residual nuisance odors that are composed of organics and reduced sulphur compounds such as dimethyl sulphide (DMS), dimethyl disulphide (DMDS), and methyl mercaptan (MM). These compounds, with low water solubility and high molecular weights are difficult to degrade biologically to meet stringent Ministry of the Environment (MOE) odor emission guidelines.

This paper describes the dewatering process, the generation and characterization of odors, and compares the odor removal characteristics of softwood bark organic media against a mineral based, permanent inorganic media. Practical operating experiences are discussed in detail and performance under a variety of conditions is examined using theoretical models. These kinetic models are used to describe the degradation characteristics of the process and can be used to predict the performance of the systems under a variety of operating conditions.

KEYWORDS: biosolids, biofilter, organic media, inorganic media, odor

DE-WATERING PROCESS

The City of Toronto Main Treatment Plant biosolids truck load-out and odor control facility has implemented a Biosolids Beneficial Re-Use Program which incorporates the containment and treatment of the odorous gases generated from the biosolids handling operations. The capacity of the facility is designed to meet the daily volume of 800 m^3 of dewatered sludge.

The biosolids truck load-out and odor control facility consists of three main areas: the silo bulk sludge storage facility; the truck loading facility, and the odor control facility. Dewatered biosolids cake is pumped from the existing dewatering building to three sludge tank storage silos with a combined capacity of 1200 m^3. Biosolids cake is then transferred from the sludge bulk storage silos to each of four sludge cake hoppers located in the truck loading facility. Twin screw conveyors ensure continuous feed of biosolids cake to the trucks for loading. The sludge cake is 30% total solids prior to dewatering and 70% water. Once dried, the pellets are 95% total solids and 5% water.

ODOR ABATEMENT SYSTEM

Odorous air is collected from the dewatering building, silo building, and biosolids load out facility. Each of the areas is maintained under a constant negative pressure. Collected air is conveyed via a fibre reinforced plastic (FRP) duct manifold. Air is directed through to a pre-treatment system consisting of dual-stage chemical scrubbers, followed by a hydraulic spray humidification manifold and then into a four cell biofilter system. The treatment train was designed to accommodate up to 20 m^3/s. Figure 1 schematically presents the odor abatement system.

Collection

The silo building, truck loading facility, and dewatering building air is exhausted at a constant rate of 4.2 m^3/s. The truck loading area and sludge hopper ventilation system are exhausted at a rate of 6.0 m^3/s during non truck loading and at 12.0 m^3/s during truck loading. The exhaust fan is interlocked with the scale and truck loading door operation. With this configuration and control philosophy, fugitive emissions from the operation of the biosolids loading process are minimized.

Pre-treatment

The scrubber system can be operated in series, parallel, individually, or in by-pass mode. The scrubber system is designed as a roughing stage to oxidize compounds, like hydrogen sulphide and organic sulphides, using sodium hypochlorite as the oxidizing agent and sodium hydroxide to control the pH of the scrubbing solution. The scrubber is packed with 3.5” Lanpac packing which is sprayed with the scrubbing solution using a spray nozzle distributor at the top of the packed bed section. Carry over of liquid droplets from the packed bed sections, which may contain residual chemicals, into the biofilter is minimized using a polypropylene mesh pad style mist eliminator.

Once entrained water droplets are removed, the air is directed through a secondary humidification chamber to ensure that the collected air is saturated. The humidification chamber consists of a single horizontal chamber outfitted with dual spray manifolds. A centrifugal pump is employed to raise the water pressure to the appropriate value to ensure adequate atomization of the water droplets. The spray header delivers fifteen litres per minute (4GPM) to the process air, co-currently, to reach the required >98% relative humidity. The primary function of this additional humidifier is for adding moisture to the air stream when chemical scrubbers are not in operation.

Biofilter

Originally, the biofilter system employed an organic based media consisting of a pre-composted hardwood and softwood bark nugget formulation (BIOMIX^{TM}). This proprietary blend of organic materials was supplied by BIOREM and guaranteed for two years. The humidified air is directed through the forced draft biofilter system fans along approximately one hundred metres of FRP ducting. Two 150 HP radial bladed FRP fans are used as the motive force. Each fan is controlled using a variable frequency drive, interlocked with the exterior truck loading access doors, to control the flow of air to the biofilter system. The air is then distributed to the four (4) in ground biofilter cells. Table 1 summarizes the key physical specifications of the biofilter system.

Table 1: Biofilter Specifications

<table>
<tr><td>Manufacturer</td><td colspan="4">BIOREM Technologies inc., Guelph, ON</td></tr>
<tr><td>Type</td><td colspan="4">In-Ground, Header/Lateral System</td></tr>
<tr><td>Configuration</td><td colspan="4">Forced Draft/Upflow/Open Top</td></tr>
<tr><td>Commissioned</td><td colspan="4">March 1, 2000</td></tr>
<tr><td>Treatment Capacity</td><td colspan="4">20 m^3/s (45,000 CFM)</td></tr>
<tr><td>Number of Biofilter Cells</td><td colspan="2">4</td><td colspan="2">3*</td></tr>
<tr><td>Retention Time</td><td colspan="2">60 sec</td><td colspan="2">45 sec</td></tr>
<tr><td>Cell Capacity</td><td colspan="2">5.0 m^3/s
(11,250 CFM)</td><td colspan="2">6.67 m^3/s
(15,000 CFM)</td></tr>
<tr><td rowspan="2">Cell Dimensions</td><td>Length</td><td colspan="2">Width</td><td>Depth</td></tr>
<tr><td>26 m
(85 ft)</td><td colspan="2">17.4 m
(57 ft)</td><td>0.9 m
(3 ft)</td></tr>
<tr><td>Media Volume</td><td colspan="4">1,200 m^3 (42,000 ft^3)</td></tr>
<tr><td>Superficial Velocity</td><td colspan="2">0.011 $m^3/m^2/s$
(2.32 $ft^3/ft^2/min$)</td><td colspan="2">0.015 $m^3/m^2/s$
(3.10 $ft^3/ft^2/min$)</td></tr>
<tr><td rowspan="2">Media Type</td><td colspan="4">Originally- BIOMIX^{TM}, premium organic media</td></tr>
<tr><td colspan="4">Currently- BIOSORBENS^{TM}, permanent, mineral based media</td></tr>
</table>

* Cells required for full flow, one redundant. Typically operated with all four cells in service.

Each of the four biofilters cells is provided with a manually operated zero-leakage control damper for balancing airflows. A cell can be removed from operation for maintenance without impacting odor removal performance. Each cell is formed using a high density polyethylene liner appropriately installed on a sand base. A central duct brings the foul air to a header that runs the length of each cell and has approximately two dozen perforated laterals running perpendicular to the header as shown in Figure 2.

The lateral ducts are bedded in an aggregate base to aid with appropriate air distribution and leachate drainage. Each cell is equipped with a surface irrigation system to ensure that the biofilter media retains sufficient moisture for effective microbial activity. Excess moisture from either irrigation or precipitation is drained by gravity from each of the four cells into a common process sump. The process sump consists of a two chamber, below grade precast concrete reactor. The first chamber is used as a neutralization stage, using a limestone percolation system to neutralize the low pH biofilter leachate generated from biological oxidation of the odor-causing compounds. The second chamber contains two submersible pumps that discharge the leachate into a force main for disposal.

The City of Toronto subsequently completed two organic media change-outs when the media was deemed beyond its useful life before deciding to proceed with replacing the organic media in the fall of 2004 with a permanent inorganic media that is mineral based (BIOSORBENS*TM*). This synthetic media was also supplied by BIOREM and carries a 10 year, non-prorated warranty. The BIOMIXTM media had a useful life of about 3.5 years before is replaced.

Specified Design Requirements
The original design criteria are shown in Table 2 with the original BIOMIXTM media in place. The design parameters were verified upon system performance testing during commissioning. The performance test was required to be performed at the design flow with the upstream processes in operation.

Table 2: Design and Measured Loading Rates of the Odor Control System

Contaminant	Specified Design Condition	Measured Inlet Condition*
Hydrogen Sulphide (H_2S), ppb	5,000	ND
Methyl Mercaptan (MM), ppb	6,000	750
Dimethyl Sulphide (DMS), ppb	15,000	930
Dimethyl Disulphide (DMDS), ppb	5,000	550
Odor, OU/m^3	500	114,227

*Inlet conditions measured during system commissioning when first installed in the spring of 2000

COMPARISON OF ORGANIC MEDIA AND INORGANIC MEDIA

When selecting a biofilter media, the Owner must consider a variety of issues related to media life, performance, and life cycle costs. This section describes some of the issues and differences between organic and inorganic media. Traditional organic media typically consists of a blend of wood bark, soil, animal manure, compost, or peat[1]. Organic media has a short active life as a biofilter media. After some time, the organic material will degrade to a point where air can not pass through the media without a large fan to move the air through it. At this point, it is not economical to operate the system. As well, the air moving through the system may only be partially treated due to the preferential air paths through the system.

Inorganic biofilter media is not biodegradable[2]. The inorganic support structure retains its shape to ensure that the process air can easily pass through it with out the need for fans with high static pressures. Inorganic media can also be manufactured in such a way to control the quality of the media. It allows incorporation of specific components to improve the biofiltration efficiency and provides consistent and long term biofiltration performance.

Moisture is a critical factor for phase transfer of odorous compounds to the biofilm which allows the bacteria access to the compounds. Uniform moisture distribution is important to ensure even air distribution throughout. Organic media can hold excess amounts of moisture, is difficult to re-wet in the event it dries out, and shrinks and swells with varying moisture contents. Inorganic media moisture can vary but the media does not change shape and the air flow distribution is not affected. The system operating therefore remains more stable and odor destruction efficiency remains more consistent. In the event that the media moisture drops below the recommended operating range, optimum media moisture is easily recovered with humidification and surface irrigation.

Media compaction caused by microbial activity increases pressure losses and consequently increases fan energy consumption. Compaction can also impact air distribution and system performance. Organic media degrades within 6 months to 3 years – a function of microbial activity which is directly related to the odorous influent load, process air temperature, moisture, and other process conditions. Inorganic media can last for 20 years and longer due to the non-biodegradable inorganic support structure.

The surface area of the media is required to ensure the odorous compounds are transferred from the air phase onto the media and allows for easy attachment of microbial colonies. Organic media has limited available surface area, typically 0.5-1m^2/g. Inorganic media can be manufactured to have a specific surface area that is much greater than organic media. The engineered media surface area is controlled in the manufacturing process and is typically greater than 40m^2/g. The surface areas were measured using a Quantachrome Autosorb-3, to determine the surface area by B.E.T. analysis. The analysis was conducted by Particle Technology Labs.

The pH of media is important to maintain a healthy microbial population. Biological activity will generate protons that will drop the pH of the media. The continuous break down of organic media will also generate acid by-products that lower the pH which organic media is not able neutralize. Inorganic media has a buffer that is manufactured into the product to ensure neutral pH operation and biological oxidation of a wider variety of odor causing compounds. When the pH of a biological odor control system is not operating in the neutral range, the solubility and microbial efficiency decreases significantly. Thus the odor removal efficiency also decreases.

Macronutrients are required for the growth of the microbes that acclimate to the process conditions. Organic media has some naturally occurring nutrients that are available to the microbes. The organic media nutrients are dependant on the source of the organic material and are prone to nutrient leaching. Inorganic media is formulated with a specific blend of nutrients to encourage the growth of specific microbes for the biofiltration application. The nutrients are blended in the correct proportions to release the nutrients slowly for the media life.

As discussed, the physical properties of the media are important. The following table (Table 3) summarizes and compares the key media parameters for both media types. The inorganic media properties are controllable as a manufactured product. The differences between the two media types are due to calculated changes that were required to meet the described deficiencies of organic media.

Table 3: Media Property Comparison

Parameters	Organic Media - BIOMIX™	Permanent Inorganic Media - BIOSORBENS™
Density	600-750 kg/m^3	750-800 kg/m^3
Surface Area	0.5-1.0 m^2/g	40-100 m^2/g
Moisture Content	100-300% m/m	20-40% m/m
Differential Pressure	820 Pa/m (1"/ft)	205 Pa/m (0.25"/ft)
Design Velocity	0.025 - 0.051 m/s (5-10 ft/min)	0.025 – 0.102 m/s (5-20 ft/min)
Particle Size Analysis	<100mm (4-inch)	<20mm (3/4-inch)
Formulation	hardwood/softwood bark pre-composted	mineral based coated aggregate
Longevity	1-3yrs	10-20yrs
Guarantee	2yrs	10yrs

PERFORMANCE COMPARISON

Media Pressure Drop and Energy Considerations

As organic media degrades, the fine particles that result restrict the air flow through the media. To maintain the desired air flow, more static pressure is required from the fan to push the air through the media. The resulting effect is an increase in the media differential pressure. Inorganic media is not biodegradable. Thus the differential pressure will not increase due to decomposition. Figure 3 shows the differential pressure of both organic and inorganic media when it is first placed into service. It also shows the organic media pressure drop after several years of use and it has biologically degraded. Figure 3 was generated using the Ergun equation[3] shown below as Equation 1. Table 4 shows the values for the chart that was generated. Assumed values are indicated in the chart.

Equation 1: Ergun Equation

$$\frac{\Delta P}{L} = \left[\left(\frac{1-\varepsilon}{\varepsilon}\right)\frac{\rho V_S^2}{D_P}\right]\cdot\left[\frac{150(1-\varepsilon)\mu}{D_P V_S \rho}+1.75\right]$$

where,

μ - viscosity of air at STP, 1.81x10-5 $kgm^{-1}s^{-1}$

ρ - density of air, 1.2 kgm^{-3}

D_P – mean particle size diameter

ε - void space

V_S – superficial velocity

Table 4: Ergun Equation Variables

	BIOMIX™		BIOSORBENS™	
	Fresh	Year 3	Fresh	Year 3
D_p	0.05	0.05	0.01	0.01
ε	0.095*	0.01*	0.25	0.25

*assumed based on particle size analysis

The pressure loss that occurs as the air flows through the media relates directly to fan horse power and energy cost. The more back pressure inherent in the system, the more electrical energy required to push the air through the biofilter media.

Modelled System Performance

The performance of a biofilter can be modelled to predict the system performance and to accurately size a system for specific applications. Figure 4 shows the system models for organic media and inorganic media at a 60 second empty bed residence time (EBRT) for H_2S. Odor is much more difficult to model as odor is a mixture of a variety of compounds. Thus a given odor concentration can have many different combinations of compounds to achieve the same odor concentration. The most appropriate model for this compound and both biofilter medias was determined to the zero order diffusion-limited model[4] shown in Equation 2. The various process conditions and media properties are taken into consideration by the various parameters of the equation. These are not typically individually determined but are often lumped together and estimated with experimental data. For example, media moisture is accounted for by the liquid phase diffusion coefficient.

Equation 2: Zero Order Diffusion-Limited Model

$$\frac{C_g}{C_O} = \left(1 - \frac{zA_S}{v}\sqrt{\frac{KD}{2HC_0}}\right)^2$$

Where,

C_g = outlet concentration
C_o = inlet concentration
Z = media bed depth
A_S = surface area per unit volume
v = gas velocity
K = zero-order reaction rate
D = liquid phase diffusion coefficient
H = Henry's Law coefficient

The system model shows that for the organic media, 99% removal is achievable for concentrations up to 40 PPM. As the concentration of H_2S increases, the system performance decreases exponentially. The organic media performance model is variable due to the fact that it is a natural product which has inherent variability beyond the control of the media supplier/manufacturer. Variations in particle size, available nutrients, surface area, and moisture content will all affect the performance model.

Inorganic media performance is predictable. It is a manufactured product where the properties of the media are controlled. Available nutrients, surface area, moisture content, and particle size are manufactured to a specification which allows for repeatable and predictable system performance. The model in Figure 4 shows improved performance of the inorganic biofilter media over organic media, providing 99% removal of H_2S up to 125 PPM H_2S.

H_2S removal at the high concentrations as shown in Figure 4 is possible but not practical for long term performance. Pretreatment of high H2S load maybe more suitable. The ability to remove H_2S as predicted with the diffusion limited model indicates that the organic based media is limited due to diffusion, thus surface area, moisture content of the liquid phase biofilm, and bed depth are some of the factors that affect this performance. H_2S as a surrogate indictor for odor removal of a specific media can be improved by modifying the aforementioned variables. The BIOSORBENS™ media has been formulated to ensure that these parameters have been optimized and thus provide superior H_2S and odor removal.

Initial System Performance
The system was performance tested in May 2001. The original performance data is shown in Table 5. The total system odor removal performance and the organic biofilter media performance were exceptional. The biofilter performance is calculated to be 85.3% with a biofilter outlet odor of 620 OU. Once the scrubber systems were taken off-line, the full odor load was treated by the biofilter.

Table 5: Initial Performance Testing Results

Description	Flow (m^3/s)	Odor (OU/m^3)
Scrubber Inlet	-	114,227
Biofilter Inlet	18.2	4,237
Biofilter Outlet	-	620
Biofilter Removal Efficiency	-	85.3%

Current Biofilter System Performance
The current performance of the biofilter at the Ashbridges Bay WWTP was modelled to show the variability in the system performance. The system was modelled based on the odors from the process air in and out of the system. The odorous air was determined to comprise mainly of the reduced sulphur compounds methyl mercaptan (MM), dimethyl sulphide (DMS), and dimethyl disulphide (DMDS). Figure 5 illustrates the comparative performance of the organic and inorganic media. Current data was collected from the system to validate the models and is collected on a continual basis. Data is typically collect during the high odor season of the summer. The model was generated in the same fashion as the H2S model presented in Figure 4. Odor samples were evaluated in accordance with the Ministry of the Environment Draft “Source Sampling for Odors”, Version #2, February 1989, using an AC’SCENT International triangular forced-choice, ascending concentration, dynamic dilution Olfactometer. All samples were retrospectively screened as required by the European Standard EN 13725:2003. The reduced sulphur compounds were analyzed using an HP 5890SII GC as per reference methods Environment Canada Report EPS 1/RM/6 and ASTM method D5504-01. Inlet and outlet samples were collected simultaneously. Variability in the inlet concentrations are due to process changes between sampling of the individual biofilter cells.

The inorganic media system is able to achieve 99% odor removal in 60 seconds of EBRT. Odor models are hard to generate for general process conditions. This model is applicable to this system at this point in time as the conditions and composition of the odor causing compounds are variable. The performance of the organic media is less efficient than the inorganic media. The organic media was installed about 4 years prior to the inorganic media. Over time the media degrades to a point where the removal efficiency is severely affected. This is due to the organic nature of the product and that it degrades over time making it difficult for air to pass through the media and short circuit with out being treated. This is resolved with inorganic media as it does not degrade, is of uniform size and the possibility of air by-pass is eliminated.

The odor removal data is shown in Figure 6. It shows a significant performance difference between the organic and inorganic media. The poor performance of the organic media is a function of its useable life. The data shown uses organic media that is about 4-5 years old. The poor performance can be attributed to the poor air flow distribution through the biofilter media and uneven moisture distribution. The inorganic media continues to provide excellent odor removal with residual outlet odor being less than 100 OU.

The major odor causing compounds were found to be methyl mercaptan (MM), dimethyl sulphide (DMS), and dimethyl disulphide (DMDS). These compounds are typical of biosolids odors. The removal of each compound is shown in Figure 7.

DISCUSSION

The odors associated with biosolids processes are typically characterized as complex mixtures of a variety of compounds, including some that are recalcitrant to degradation and others that have reduced water solubility. Given the low detection thresholds and the difficulty in treating these compounds, an effective capture, collection, an odor abatement system requires careful consideration.

The study of a full-scale field-erected biofilter system, operated with two different types of media, on the complex process air from a biosolids handling facility demonstrates and confirms several conclusions:

1. Biofilters can effectively treat the odours;
2. Performance attributes of organic versus inorganic media differ greatly.

Organic media has been demonstrated to be an effective substrate for microbial immobilization. However, the physical and operational disadvantages associated with the good biological environment are summarized below:

1. Media performance declines with age. The media is structured predominantly from a mixture of organic materials that provide an additional carbon source for the bacteria. As the microfauna degrades this material, the mean particle size reduces, causing increased backpressure and the potential for channelling. This also reduces the effective contact time within the reactor, impacting odor removal efficiencies.
2. Media requires replacement. The degradation of the media leads to compaction and preferential flow paths to develop. This will lead to a situation where the organic media will need to be removed and replaced with fresh media. For this application, the average lifespan of a cell with organic media was three years.
3. Energy consumption. As the mean particle size decreases, frictional resistance to air flow also increases. This increase is exacerbated with compaction and moisture content. Frictional losses can greatly increase the year to year operational costs of a biofilter with organic media.
4. Odor destruction performance is related to the composition of the process air stream. Compounds with low water solubilities or complex molecular structures have much lower destruction efficiencies. This is most likely due to the mechanisms of reduced phase transfer and oxidative potential. The performance of the organic media was excellent for easy to degrade contaminants such as methyl mercaptan, but was very poor for the more difficult DMS and DMDS compounds.

The use of the inorganic media, BIOSORBENS® has demonstrated improved performance under a variety of loading conditions and can greatly reduce overall life cycle costs of a biofilter odor control system. The following general conclusions were made from the comparison:

1. Reduced operational costs. Given the rigid structure of the synthetic media, compaction and variations in particle volume due to moisture fluctuations does not occur. This maintains a consistent and reduced differential pressure- which equates to lower energy consumption. Media replacement is not required and a conservative effective lifespan is anticipated at being fifteen to twenty years.
2. Consistent performance. Over the course of the study, the performance (both odor destruction and energy consumption) did not vary. The study will be continued into the future to confirm performance after five and ten years. This will help confirm the preliminary conclusions being made in this report.
3. Increased performance over a wider variety of contaminants. DMS and DMDS destruction performance was orders of magnitude greater. This is especially critical for municipal applications involving sources of air related to biosolids handling. Performance on total odor removal was greater than with organic media, even with reduced retention times.

Implications

1. Life cycle costs need to evaluate the energy consumption of various types of medias and reactor designs. The evaluation should also include the costs associated with removing, replacing and disposing of the organic media.
2. Reduced retention times are possible when using a high-quality, properly formulated inorganic media. In this case, the study compared the use of organic media with BIOSORBENS® permanent, inorganic media.
3. A smaller, compact reactor design with reduced retention time, deeper media depth is more likely to aid with reducing overall installed capital costs of an abatement system.

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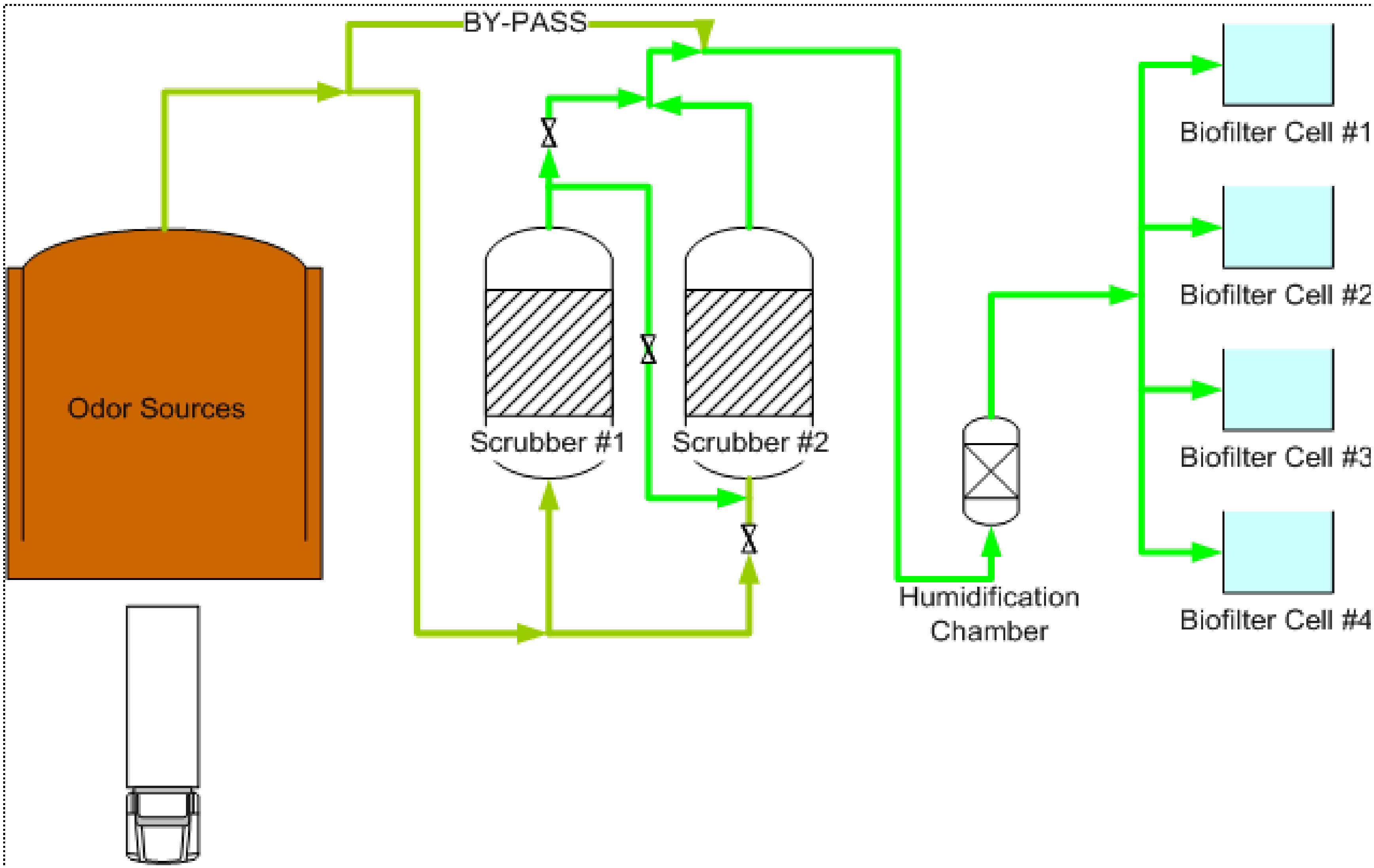

Figure 1: Odor Control System Process Flow Schematic

Figure 2: Header/Lateral Biofilter Configuration

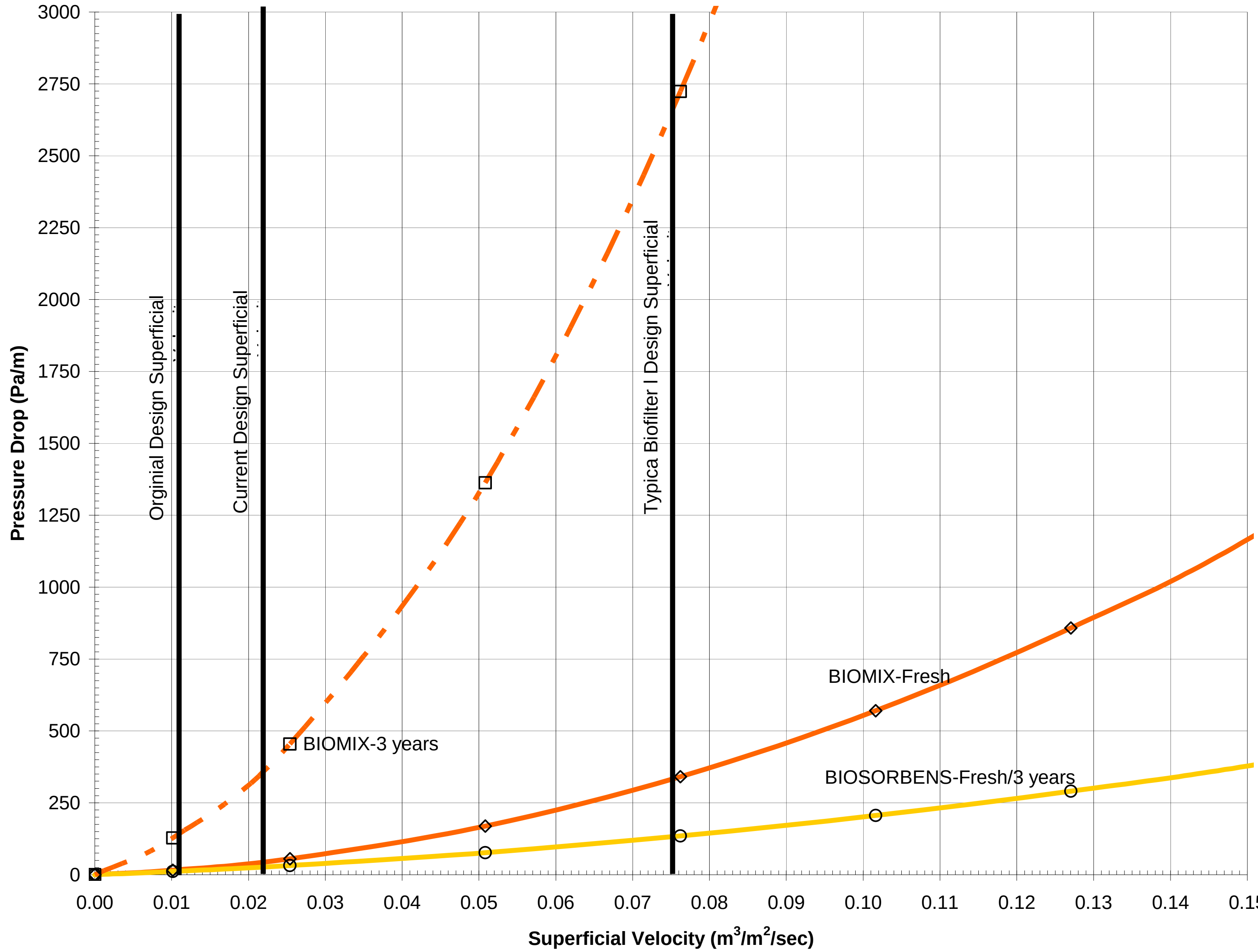

Figure 3: Pressure Drop of BIOMIX™ and BIOSORBENS™ Biofilter Media

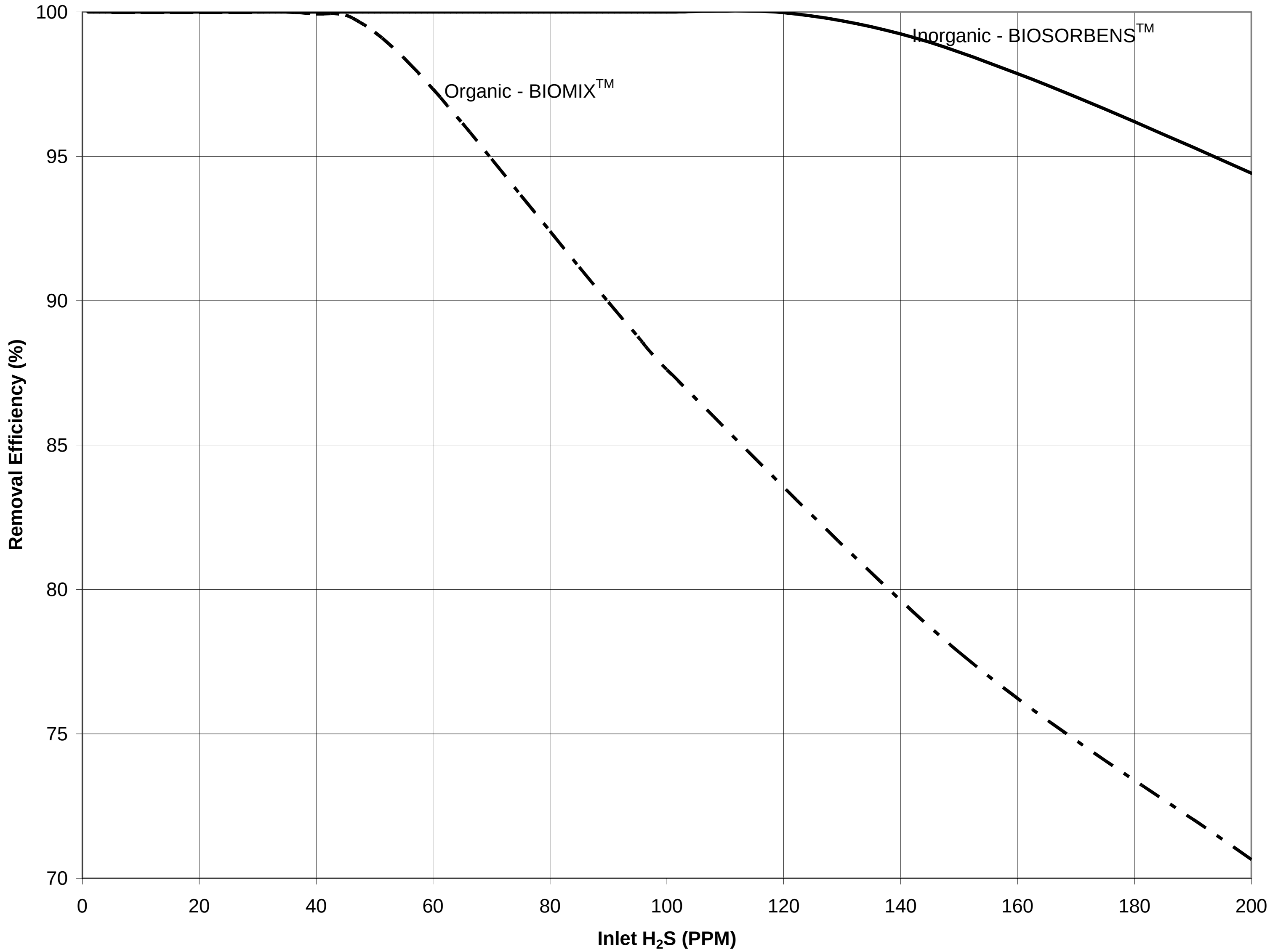

Figure 4: System Model of Organic and Inorganic Biofilter Media for H_2S

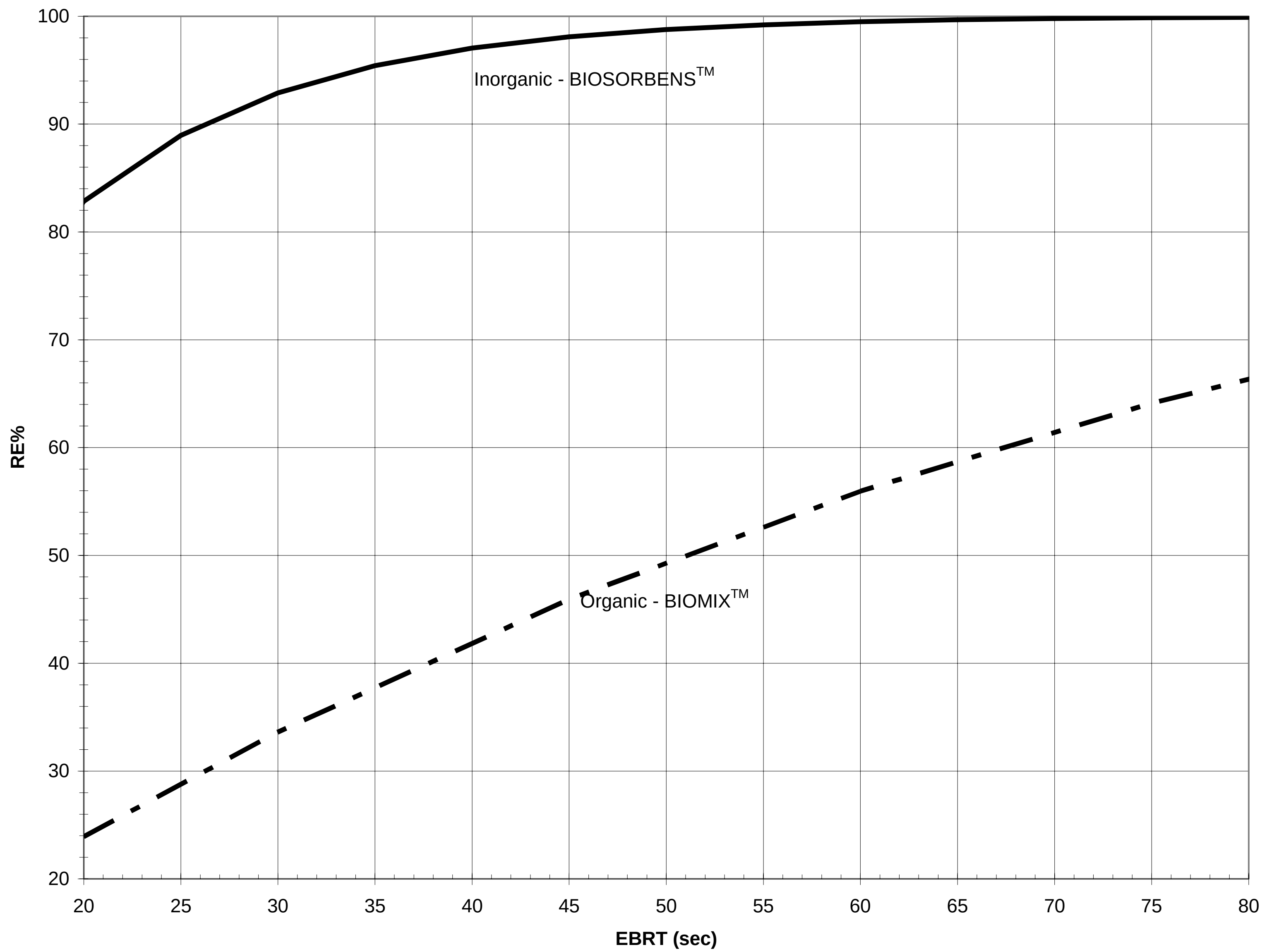

Figure 5: Odor Performance Model of Organic and Inorganic Biofilter Media

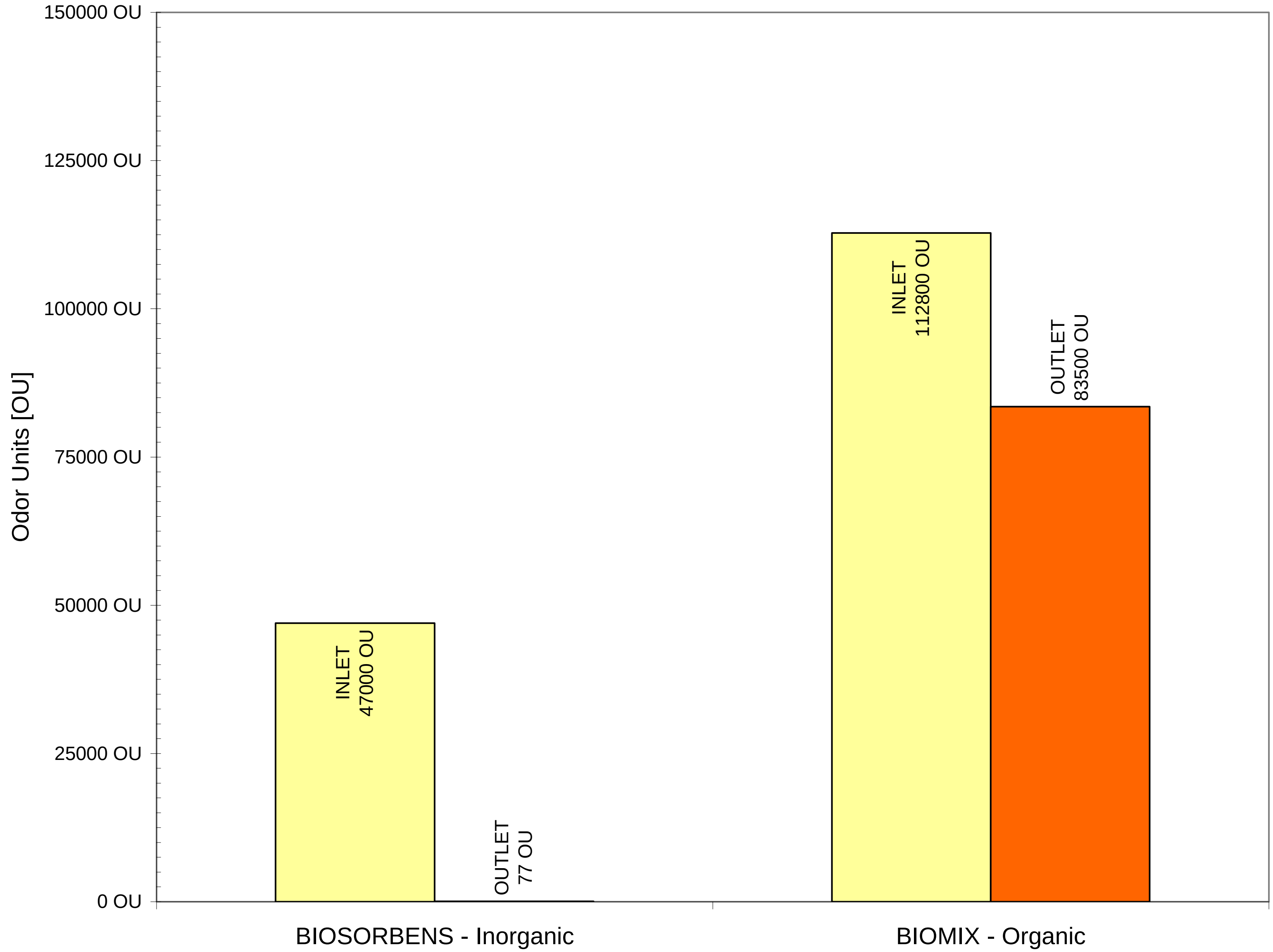

Figure 6: Odor Removal of Inorganic and Organic Biofilter Media

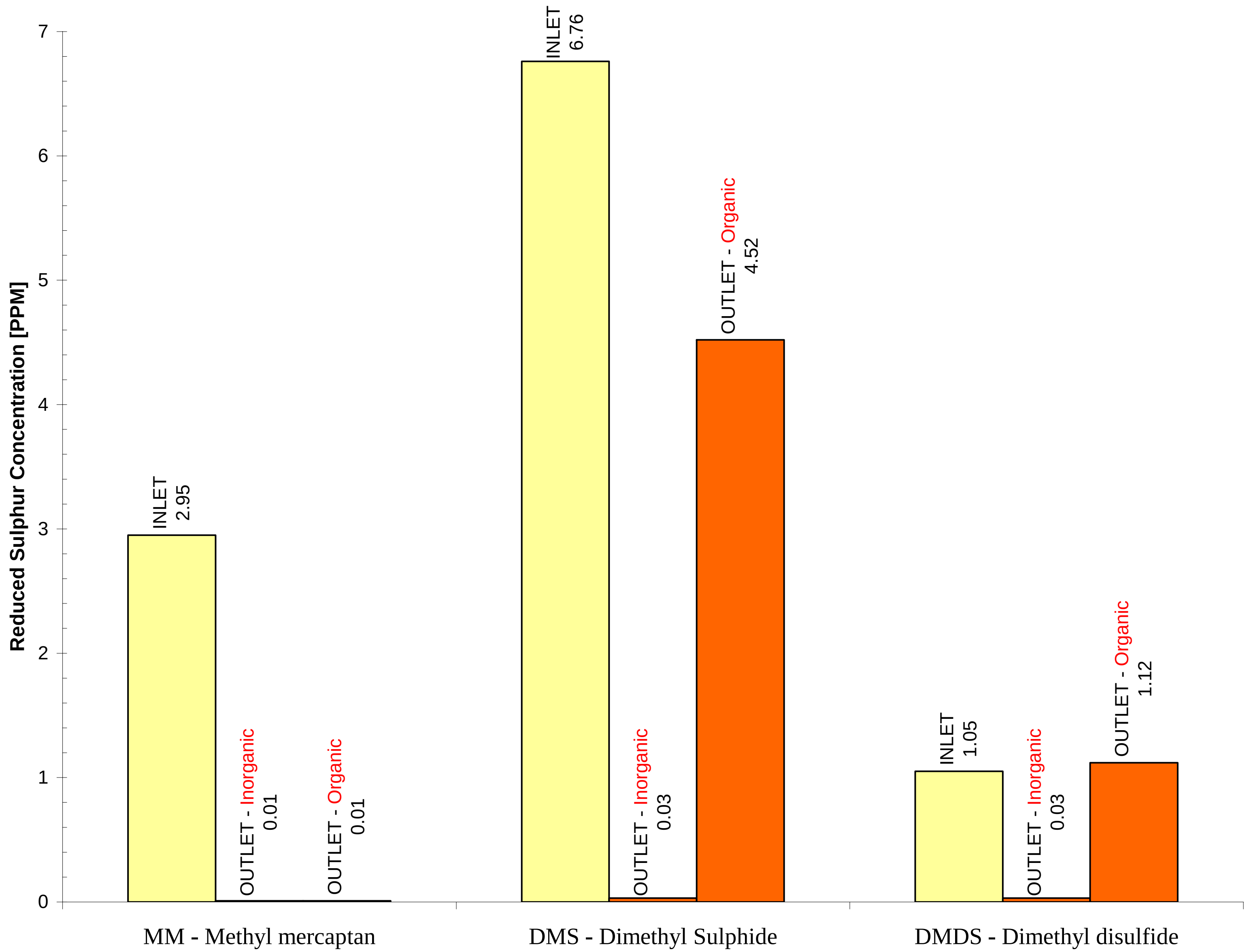

Figure 7: Odor Characterization and Destruction Efficiency