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A Review on use of Biofilters in Air Pollution Control

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ABSTRACT: In this paper the review of the existing air pollution control technologies was done essentially for the elimination of volatile organic compounds (VOC). The biotechnologies referred to, bioscrubbers, biotrickling filters and bio-filters are also described. A more detailed review of biofiltration is proposed, presenting the most recent and latest developments achieved in the field of bio processing. In particular, the influence of the filter bed, the polluted air flowrates, the pollutants, the pressure drop, and bed moisture content, temperature, nutrients, pH and the microorganisms are reviewed. Models of biofiltration are also presented. A literature study was conducted to compare the feasibility of biofilters and biotrickling filters for the treatment of complex odorous waste air containing hydrogen sulfide (H_2S), organic reduced sulfur compounds, and chlorinated and non-chlorinated volatile organic compounds (VOCs). Pilot-plant studies and full-scale applications at wastewater treatment plants and other facilities were reviewed. Reactor design and pollutant removal efficiencies were summarized

KEY WORDS: Volatile Organic Compounds (VOC), Biofilters, Biotrickling filters, bioscrubbers

I. INTRODUCTION

Traditional air pollution control technologies for pollutant gases, such as adsorption, absorption and combustion, were developed to treat high concentration waste gas streams associated with process emissions from stationary point sources. Although these technologies rely on established physio-chemical principles to achieve effective control of gaseous pollutants, in many cases the control technique yields products which require further treatment before disposal or recycling of treatment materials. In the case of treatment of dilute waste gas streams, however, these traditional methods are relatively less effective, more expensive and wasteful in terms of energy consumption; and identification of alternative control measures is warranted. A suitable alternate air pollution control technology is bio filtration, which utilizes naturally occurring microorganisms supported on a stationary bed (filter) to continuously treat contaminants in a flowing waste gas stream.

Bio filtration is a relatively recent air pollution control (APC) technology in which off-gases containing biodegradable volatile organic compounds (VOC) or inorganic air toxics are vented through a biologically active material. This technology has been successfully applied in Germany and The Netherlands in many full-scale applications to control odors, VOC and air toxic emissions from a wide range of industrial and public sector sources. Control efficiencies of more than 90 percent have been achieved for many common air pollutants. Due to lower operating costs, bio filtration can provide significant economic advantages over other APC technologies if applied to off-gases that contain readily biodegradable pollutants in low concentrations. Environmental benefits include low energy requirements and the avoidance of cross media transfer of pollutants.

Bio filtration is a relatively emerging new technology, applied to wastewater treatment and other toxic compounds. Since the main purpose of the bio filter is to remove the dissolved organics, the suspended particles are removed in conventional filter before subjecting the waste water. The parameters that can affect the performance of a bio filter are the characteristics of filter media, hydraulic and organic loading rate, and filter backwash techniques. The mechanisms, which allow bio filters to work and which must be controlled to ensure success, are complex. Ultimately, biotransformation converts the contaminant to biomass, metabolic by-products or carbon dioxide and water.

1.1 WHAT IS BIOFILTRATION?

Biofiltration is a relatively new pollution control technology. It is an attractive technique for the elimination of malodorous gas emissions and of low concentrations of volatile organic compounds (VOCs).

The most common style biofilter is just a big box. Some can be as big as a basketball court or as small as one cubic yard. A biofilter's main function is to bring microorganisms into contact with pollutants contained in an air stream. The box that makes up this biofilter contains a filter material, which is the breeding ground for the microorganisms. The microorganisms live in a thin layer of moisture, the "biofilm", which surrounds the particles that make up the filter media. During the biofiltration process, the polluted air stream is slowly pumped through the biofilter and the pollutants are absorbed into the filter media. The contaminated gas is diffused in the biofilter and adsorbed onto the biofilm. This gives microorganisms the opportunity to degrade the pollutants and to produce energy and metabolic byproducts in the form of CO₂ and H₂O.

This biological degradation process occurs by oxidation, and can be written as follows:

Organic Pollutant + O₂ → CO₂ + H₂O + Heat + Biomass

1.2 Importance of Bio-filtration

- The process involved (bio reaction) is a green process.
- Thermal and catalytic control units consume large volumes of expensive fuel.
- Bioreactors only use small amounts of electrical power to drive two or three small motors.
- Normally, bioreactors do not require full-time labor and the only operating supplies needed are small quantities of macronutrients.

1.3 Types of Bio Filters

1.3.1 On The Basis Of Layout:

- Open Bed : Uncovered and Exposed to all Weather conditions.
- Closed Bed: Enclosed with a small exhaust port for venting of cleaned air

1.3.2 On The Basis Of Shape

- **Horizontal biofilters:**
 - These are designed to have a larger footprints
 - These are relatively inexpensive and the cost of setting up is easy.
 - Moreover these type of biofilters are easy maintain.
- **Vertical biofilters:**
 - These are designed to reduce the footprint required.
 - This type of biofilters Use less surface area compared to Horizontal
 - Compared to others, this type of biofilters is expensive.
 - Also this filter is not easy to maintain.

1.3.3 On The Basis Of Support Media

- Compost Bio Filter: Soil, Peat, Compost material is used
- Synthetic Bio Filter: Ceramic, Plastic (BTX)

II. PROCESS DESCRIPTION

Biofiltration utilizes a supported media for microbial growth to remove odors and organic contaminants from air streams. The filter consists of a closed chamber containing contaminant degrading microbes and absorbed water suspended in a filter medium. The filter media is designed to provide a high capacity for water uptake, have a long working life, and provide a low pressure drop for the gases passing through the media.

In the biofiltration process, contaminated air is moistened by a humidifier and is pumped into the biofilter through a chamber below the filter medium. While the air slowly flows upward through the filter media, the contaminants in the air stream are absorbed and metabolized. The purified air passes out of the top of the biofilter and into the atmosphere. Most biofilters that are in operation today can treat odor and VOCs with efficiencies greater than 90%. However, the

drawback to this technology is that it can only handle low concentrations of pollutants (<1000 ppm) and loading rates between 300-500 ft³/ft²-hr.

2.1 Biofilter media:

The moist filter medium provides physical and chemical conditions appropriate for the transfer of contaminants from the air to the liquid phase and the biodegradation of the contaminants in the biofilm layer. The mechanism of the biofiltration process includes a combination of adsorption, absorption and microbial degradation. Microorganisms contained in the biofilm layer continually metabolize the contaminants, as they are absorbed, converting them ultimately to water, carbon dioxide and salts.

Typical biofilter media material includes compost-based materials, earth, heather, plastic, or wood-product based material. The purpose of the biofilter media is to provide a large surface area for the absorption and adsorption of contaminants. The media also serves as a nutrient source for the microbial population. In fact, some types of media lack proper nutrients and will require the manual addition nutrients (e.g. nitrogen and phosphorous compounds) in order to sustain microbial life. Most biofilters will operate for 5-7 years before it is necessary to renew the filter media.

Major considerations when determining the appropriate filter material include:

- Ability to retain moisture to sustain biofilm layer;
- Large surface area, both for contaminant absorption and microbial growth;
- Ability to retain nutrients and supply them to microbes as required;
- Low resistance to air flow (minimizes pressure drop and blower power requirements);
- Physical characteristics, such as physical stability and ease of handling

2.1.1 Components of a Bio-filter Unit

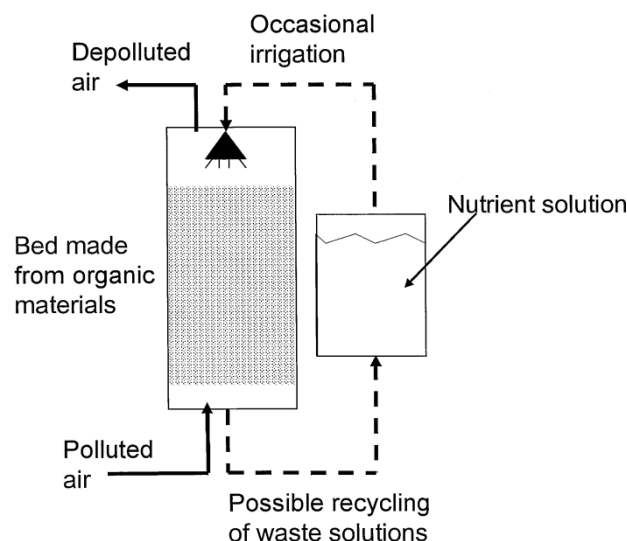


Figure no.1: Schematic Diagram of a Bio filter Unit

A biofilter, as depicted in Figure above, is a fixed-bed bioreactor, in which degrading microorganisms are immobilized. The contaminated gases flow through the porous material and the VOC biological oxidation occurs after they have diffused into the biofilm, synthesized by the micro flora. Two biofilter configurations exist:

The open designed biofilters, with ascending gas flows, installed outside because they require large spaces, and therefore exposed to climate changes.

The enclosed designed biofilters need more restricted volumes than the open configuration; they are often installed in closed rooms, and they can employ either ascending or descending gas flows. The most important physical, chemical and biological parameters influencing the biofiltration process are described in the following sections.

The most important physical, chemical and biological parameters influencing the biofiltration process are described in the following sections.

Filter Bed

The filter bed constitutes the heart of the biofiltration process because it provides the support for microbial growth. The following criteria are among the more important of the required specifications:

1. A high specific surface area, which is favorable to micro flora establishment and maintenance, and to gas/biofilm exchange
2. A high porosity to facilitate gas convection and to promote the homogeneous distribution of gases throughout the bed;
3. A good water retention capacity to avoid bed desiccation;
4. The presence and availability of intrinsic nutrients;
5. The presence of a dense and diverse indigenous micro flora.

Peats, soils, composts, and at a smaller scale wood chips, are the most frequently employed basic materials in biofiltration, because they satisfy most of the required criteria, and they are widely available and at low cost. The main advantage of soils is that they offer a rich and varied micro flora. However, they contain only a few intrinsic nutrients, they present low specific surface areas and they generate high pressure drops

Flow Rate

The air flow rate, Q , and the empty bed residence time (EBRT), τ , defined as:

$$\tau = V_{\text{bed}} / Q$$

Q (V_{bed} , is the bed volume), are parameters that have significant impact on the biodegradation performance (Elmrini et al., 2004). Indeed, two physico-chemical mechanisms may limit the overall elimination efficiency of a biofilter (Ottengraf, 1986): the pollutants diffusion transfer from gas phase to biofilm, and the biodegradation reaction.

Depending on both the flow rate and the VOC concentration, the VOC degradation process is limited by either one of these mechanisms or both simultaneously.

Pollutants

As previously mentioned, the overall biofiltration efficiency and the pollutants biodegradability level rely on the following microscopic processes: the VOC transfer rate from gas phase to biofilm, and the VOC biodegradation rate. The magnitude of both parameters depends on the operating conditions (flow rate, temperature, pH, moisture content, etc.), but also on the type and concentration of pollutants presented. The contaminants absorption in the biofilm is governed by the Henry's law, which correlates the VOC vapor pressure with its solubility in water.

Pressure Drop

The bed pressure drop is an important biofiltration parameter because it is taken into account in the operating costs. Thus, Leson et al., 1995, reported that a pressure drop increase from 4 to 25 cm of water led to an increase in energetic needs from 7 to 27 kW, within only 6 months. The pressure drops recorded in most of biofiltration systems do not exceed some cm of water/m. Several factors influence the pressure drop level through the porous filter bed: filter bed characteristics, flow rate, moisture content, biomass density, etc.

Moisture Content

From the biological viewpoint, the moisture content in the filter bed is one of the most important of biofiltration parameters. Thus, Morales et al., 1996, reported that 75% of biofiltration troubleshooting events are related to bad control of the humidity level. Indeed, water is essential for the microbial activity that takes place in the biofilm. Too low bed moisture content leads to bed desiccation and gas flow channeling, which particularly affects the micro flora

the intensity of the microbial activity in a biofilter, is related to the operating temperature. Most of the microbial populations that develop in filtering media are mesophilic (Kennedy and Thalasso, 1998), which implies that the optimum temperatures range between 20 and 40°C. Park et al., 2002, have determined that the maximum toluene degradation rates were obtained at between 30 and 35°C. This optimum temperature interval was also demonstrated by Lee et al., 2002, for the removal of BTEX

Nutrients and pH

Microorganisms established in biofilters are essentially composed of carbon, oxygen, nitrogen, hydrogen, phosphorus, and sulfur (Scriban, 1993). The pollutants introduced into the biofilters are the main carbon and energy sources for the microbial activity. Hydrogen and oxygen are found in the air, in the growth medium, and sometimes in VOC. The availability of the other macronutrients (N, P, K, and S) and micro-nutrients (vitamins, metals) depends on both the characteristics of the filtering materials and the biofilter configuration

2.2 THE BIOSCRUBBER

The bioscrubbers, as represented in Figure, consists of two subunits:

- 1) An absorption tower and
- 2) A bioreactor.

In the absorption unit, input gaseous contaminants are transferred to a dispersed liquid phase (aerosol). Gas and liquid phases flow counter-currently within the column, which may contain a packing. Nevertheless, the addition of inert packing (structured ceramic for example) provides for increased transfer surface between the VOC and the aqueous phase (Kellner and Flauger, 1998). The washed gaseous phase is released at the top of the column whereas the separated contaminated liquid phase is pumped towards an agitated, aerated bioreactor.

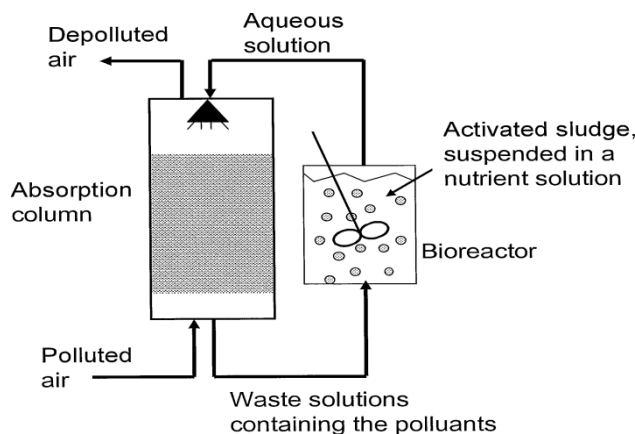


Figure no.2: Schematic diagram of Bioscrubbers

This reactor contains the degrading microbial strains suspended in the aqueous phase, and the nutrients essential for their growth and maintenance. Most of the presently operating bioscrubbers are inoculated with activated sludge, derived from wastewater treatment plants,

2.3 THE BIOTRICKLING FILTER

The description of a typical biotrickling filter is provided in Figure 3. In such a filter, the gas flows through a fixed-bed, which is continuously irrigated with an aqueous solution containing the nutrients required by the biological system. Several studies have shown that the choice of a co- or counter-current configuration for liquid and gaseous phases does not influence the biodegradation performance (Cox and Deshusses, 1998). Microorganisms are immobilized on the packing material. The pollutants are initially absorbed by the aqueous film that surrounds the biological layers

(biofilm), and then the biodegradation reaction takes place within the biofilm that gradually develops on the bed particles

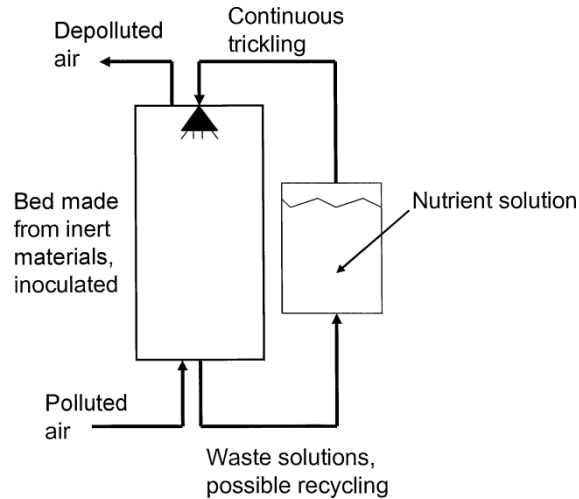


Figure no.3: Schematic diagram of Biotrickling filter

The filtering materials have to

- (1) Facilitate the gas and liquid flows through the bed and the gas/biofilm transfers
- (2) Favor the development of the micro flora, and
- (3) Resist crushing and compaction. Biotrickling filter packing's that best meet these specifications are made from inert materials such as: structured plastics, resins, ceramics, celite, polyurethane foam (Yamashita and Kitagawa, 1998), lava rock (Sorial et al., 1995; Loy et al., 1997). However, most of these materials present limited specific surface areas (between 100 and 300 m⁻¹) (Rho, 2000), with some cases >1000 m⁻¹ for polyurethane based beds. As they are made from inert or synthetic materials, biotrickling filters need to be inoculated, most of the time with activated sludge (Oh and Bartha, 1997; Lu et al., 2000). Due to the permanent trickling mechanism, biotrickling filters are "cousins" of bioscrubbers. In this way, they are more adapted for the elimination of quite soluble VOC.

III. DESIGN PARAMETERS:

3.1 Space Constraints:

Space at a site is the greatest concern during design of a biofiltration system. A small biofiltration unit can be designed to handle approximately 30 cubic-feet-per-minutes in as little space as 25 square feet, similarly, a biofiltration system designed to treat large air volumes and require space as large as a basketball court.

3.2 Chemical Constituents and Concentrations:

Analysis of chemical constituents and their concentrations are required to determine if biofiltration is a plausible alternative. Biofilters performed best when treating hydrophilic compounds in low concentrations (<1000 ppm). Some chemicals biologically degrade at low rates, such as chlorinated compounds, which require units to be oversized.

3.3 Residence Time:

Residence Time represents the amount of time the microbes are in contact with the contaminated air stream, and is defined by (Void Volume/Volumetric Flow Rate). Consequently, longer residence times produce higher efficiencies; however, a design must minimize residence time to allow the biofilter to accommodate larger flow rates. For most biofilters, residence times range between 30 seconds to 1 minute.

3.4 Humidity:

The humidity of gas stream is important for maintaining the moisture content of the biofilter media. Gas streams introduced to the biofiltration system are usually pumped through a humidifier prior to entering the biofilter. The gas entering the biofilter should be humidified to greater than 95% relative humidity.

3.5 Ph-Control:

The by-products of microbial degradation are organic acids. In order to maintain the pH of the vessel around neutral, or a pH of 7, buffering material may be added to the organic media.

3.6 Biofilter Media:

The media used in biofilters can include peat, heather, bark, composted sewage sludge, granular carbon or other suitable materials. Generally, the media should be capable of providing nutrients to the microorganisms and minimizing pressure drop. In addition, the moisture content of the biofilter media must be maintained between 30% and 60% in order to support the microbial population. In addition to humidifying the airflow, sprinkler systems are frequently installed inside the biofilter that can be controlled to maintain a suitable bed moisture.

3.7 Pressure Drop:

Pressure drop across the biofilter reactor vessel should be minimized since an increase in pressure drop requires more blower power and can result in air channeling through the media. Pressure drop is directly related to the moisture content in the media and the media pore size. Increased moisture and decreased pore size result in increased pressure drop. Consequently, media filter selection and watering is critical to biofilter performance and energy efficiency. For a typical biofilter pressure drops range between 1 and 10 hPa.

IV. RESULTS AND DISCUSSION

4.1 Biofilters Effectiveness

- The bio filters reduce odor and hydrogen sulfide up to 95%.
- It also helps in reduction of ammonia up to 80%.
- The main component of the bio filters are Microorganisms
- It Absorbs VOC's, VIC's and oxidizes inorganic gases and vapors.

4.2 Typical Biofilter Operating Conditions for Air Treatment

Parameters	Typical value
Biofilter layer height	1-1.5 m
Biofilter area	1-3000m ²
Waste air flow	50-300,000m ³ /h
Biofilter surface loading	5-500m ³ m ² /h
Biofilter volumetric loading	5-500m ³ m ² /h
Operating temperature	15-30 °C
PH of the support material	PH 6-8

Typical removal efficiencies

60-100%

4.3 Maintenance:

The operation and maintenance of the bio filtration system would require weekly site visits during initiation of operations for emits. However, after acclimation and all system problems are resolved the frequency of site visits could be reduced to the biweekly or monthly.

4.3.1 Advantages and Disadvantages of Biofiltration

Advantages of Biofiltration:

- The main advantage of using biofiltration over other more convention control methods are lower capital costs, lower operating costs, low chemical usage, and no combustion source.
- Biofiltration units can be designed to physically fit into any industrial setting. A biofiltration unit can be designed as any shape, size or as an open field with the piping and delivery system underground. In addition, biofilters can be designed with stacked beds to minimize space requirements and multiple units can be run in parallel.
- Biofiltration is versatile enough to treat odors, toxic compounds, and VOCs. The treatment efficiencies of these constituents are above 90% for low concentrations of contaminants (<1000 ppm).
- Different media, microbes and operating conditions can be used to tailor a biofilter system for many emission points.

Disadvantages of Biofiltration:

- Biofiltration cannot successfully treat some organic compounds, which have low adsorption or degradation rates. This is especially true for chlorinated VOCs.
- Contaminant sources with high chemical emissions would require large biofilter units or open areas to install a biofiltration system.
- Sources with emissions that fluctuate severely or produce large spikes can be detrimental to that of a biofilters microbial population and overall performance.
- Acclimation periods for the microbial population may take weeks or even months, especially for VOC treatment.

4.4 General Requirements for a biofilters:

- Requires continuous air flow.
- Requires consistent loading.
- Requires a humid and warm air stream
- Often requires acclimation period for media.

4.5 Commercial Applications

There have been commercial biofilters using compost-type material installed in the world over the past 15 years.

4.5.1 VOC applications to date have included the following industries:

- Chemical and petrochemical industry
- Oil and gas industry
- Synthetic resins
- Paint and ink
- Pharmaceutical industry



- Waste and wastewater treatment
- Soil and Groundwater remediation

4.5.2 Odor abatement applications to date have included the following industries.

- Sewage treatment
- Slaughter houses
- Rendering
- Gelatin and glue plants
- Agricultural and meat processing
- Tobacco, cocoa and sugar industry
- Flavor and fragrance

V. CONCLUSIONS

- Biofiltration plays very important role in control of air pollution.
- Biofilter, like all systems follows laws of conservation & mass balance.
- Biofilter is successful only when microbial ecosystem is healthy & vigorous.
- The design of biofilter system requires a detailed understanding of site, conditions, site limitations, system components & costs.

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