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Review Article

# A Review: The Description of Three Different Biological Filtration Processes and Economic Evaluation

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**Abstract:** Biofiltration is an emerging air pollution control (APC) technology that provides a cost-effective alternative to the state-of-the-art technologies, including carbon adsorption and catalytic/thermal oxidation processes. Although biofiltration has been used to control odors for more than four decades, its industrial application for eliminating volatile toxic air pollutants has only been developed during the past fifteen years. This review presents an overview on comparison of three vapor phase bio filtration processes and economic evaluation of biofiltration technology.

**Keywords**:Biofiltration, Bioscrubbers, Biotrickling filters, Conventional biofilters, Economic evaluation.

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## INTRODUCTION

Remediation of contaminated air needed to protect ecological and human health. Potentially cost-effective systems for remediating contaminated air use biological treatment to degrade or transform contaminants to innocuous residuals. Increasingly stringent environmental legislation is generating great interest in industry as to the effectiveness of biological waste air treatment techniques. This treatment is inexpensive compared with conventional techniques such as incineration or adsorption onto activated carbon. Also, biological treatment is environmentally friendly treatment is performed at ambient temperatures, and it doesn't generate nitrogen oxides or secondary waste streams. Pollutants are converts to carbon dioxide under the action of growing/resting microorganisms. This method is the choice in many instances for the control of low concentrations of odors, VOCs, or hazardous air pollutants in large air streams.

Conventional biofilters, biotrickling filters, and bioscrubbers are attractive treatment alternatives because their fundamental and operational mechanisms suggest the potential for low costs as compared to state-of – the-art technologies. Incineration of low concentration discharges, for example is expensive due to the fuel costs for the energy required to raise the air temperature. Catalytic oxidation technologies are plagued with high energy costs and catalytic poisoning. Activated carbon adsorption technology is unaffordable due to high cost of carbon regeneration or replacement. In contrast, biofilm degradation processes offer an inexpensive alternative; nonetheless their complex nature requires careful design and control strategies. In biofilm degradation process, contaminants undergo phase transfer from gas to liquid, followed by diffusion and biodegradation within the biofilm, and eventually become adsorbed onto the solid surface to varying degree. Mass transfer resistance of the pollutants from air phase to water phase and from water phase to solid phase is an important factor in the removal process. Also, poorly water soluble compounds due to their higher mass transfer resistance. Furthermore maximization of biodegradation rate requires proper microbial growth condition for establishing an active biofilm. Therefore, to optimize such complex systems, systematic engineering and scientific studies must be carried out to investigate the interrelationships among the parameters.

## DESCRIPTION OF THREE DIFFERENT VAPOR-PHASE BIOLOGICAL FILTRATION PROCESSES

Biological systems for control of volatile organic emissions have been explored extensively in the past two decades. Nowadays, there are basically three types of biofilters: conventional biofilters, biotrickling filters, and bioscrubbers. Each type of biofilters bears its distinct advantages over others in certain situations, depending on the type of pollutants o be treated. This section will discuss the current progress made by a number of researchers on the development of these three types of biofilters. A general comparison on the advantages and disadvantages of each biofilter is summarized in **Table.1.**

**Table-1: Comparison of Three Vapor Phase Bio filtration Processes**

| | Conventional Bio filter | Bio trickling Filter | Bio scrubber |
|---|---|---|---|
| Features | • Contaminated air stream saturated with water passes through a biological packed bed.<br>• Biodegradation by micro-organism immobilized on solid media. | • Liquid recirculation counters currently with gas stream.<br>• Bio degradation by microorganisms immobilized on solid media. | • Consisting of a conventional scrubber and a biological basin.<br>• Biodegradation occurs in freely suspended culture. |
| Advantages | • Low operating cost and ease of operation with less process units.<br>• More efficient for treating poorly water soluble (hydrophobic) compounds. | • pH control allows for treatment of compounds with acidifying products.<br>• Structured material as packing media maintains structural integrity of the filter bed.<br>• Continuous liquid recirculation minimizes filter clogging and pressure buildup. | • Allows for higher pollutant loading since bio reactions occur in liquid phase.<br>• More effective for treating highly fluctuating pollutant loading.<br>• No clogging problem since no solid media are used in bio reactor.<br>• pH control allows for treatment of compounds with acidifying products. |

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|---|---|---|---|
| disadvantages | • Treating low concentration of organic pollutants.<br>• Lack of pH control requires frequent replacement of filter material once the buffering capacity is exhausted.<br>• Biomass buildup likely to cause high pressure drop across the filter bed, leaking to irreversible short-circuiting problem.<br>• Lack of long-term stability unless carefully controlled. | • Treating low concentration of organic pollutants<br>• Less efficient for treating vapours with low solubility.<br>• Additional operation and maintenance (O&M) cost due to liquid recirculation system and chemical requirement.<br>• Potential development of ph gradient in the axial direction of the filter bed. | • Inefficient to treat vapours with low solubility<br>• Additional waste water to be disposed or treated |

## CONVENTIONAL BIOFILTERS

In this type of biofilters, the contaminated gas stream is forced through the packed column inoculated with microorganisms. The gas stream, which must be humidified prior to entering the biofilters to prevent filter bed drying ,may be in either up flow or down flow mode. Materials used in column packing may be natural media or synthetic media. Natural media that have been successfully used include soil, compost, peat, lava wood bark chip crushed oyster shell, or a mixture of these materials [1-3]. The most common synthetic medium employed has been granular or pelletized activated carbon[4-7]; however other non adsorbents such as anthracite[4] have also been applied.

Microorganisms immobilized on the particles form a biofilm. As the contaminated gas is passed through a biofilter, the gaseous pollutants undergo phase transfer as they are absorbed into the biofilm. Within this biofilm, the pollutants are either biodegraded or transported near the solid surface, where they are eventually adsorbed onto the surface. In steady state operation the rate of biodegradation must exceed the rate of adsorption/absorption in order to maintain good biodegradation efficiency [8, 9].

## BIOTRICKLING FILTERS (BTF)

Biotrickling filters, also known as “fixed-film scrubbers”[10-12] and “vapor phase bioreactors,”[13] use a continuous liquid phase recirculation system through the filter bed. Conventional biofilters have the distinct advantage for treating poorly water soluble gases since mass transfer resistance (from gaseous phase to liquid phase) is minimized[14, 15]. However, a significant problem which causes irreversible deterioration of filter bed arises when acidic intermediate by products accumulate on the packing material. By recirculating liquid through the packed bed, the pH of the filter bed can be easily monitored[16, 17] and controlled by automatic addition of a base such as sodium hydroxide. Several researchers have addressed this advantage by successfully treating chlorinated hydrocarbons such as dichloromethane (DCM) [14, 15,18,19,20].

The development and testing filter using structured synthetic materials has attracted researchers` attentions. Synthetic packing materials (e.g., plastic, ceramic, and activated carbon) provide more uniform surface area and porosity, allowing better operational control, such as gas distribution, pressure drop, as well as pH and nutrient balance.

### BIOSCRUBBERS

Bioscrubber, also known as suspended-growth bioscrubber[11, 21], couples traditional air pollution control and wastewater treatment technologies. Atypical bioscrubber[1] consists of two units: a scrubber and a biological treatment basin. The soluble waste gases and oxygen are continuously absorbed into water in the scrubber.

Subsequent biological oxidation of the water exiting the scrubber occurs in the bioreactor unit which is similar to an aeration basin of an activated sludge process.

Bioscrubbers are most commonly used when the biodegradation products would harm a biofilter bed, specifically acid-producing compounds such as hydrogen sulphide and chlorinated organics. In addition, bioscrubbers are more suitable to treat highly fluctuating pollutant loads. Ottengraf[22] proposed an approach using separate absorbers and bioreactors. Over camp et al.[11, 21] further refined the design, and subsequently developed an integrated theory to describe the steady state operation of a bioscrubber for the control of VOCs. Multiple-stage absorbers were employed in their investigation, and the results obtained from the theoretical predictions indicated that the system is generally limited by the rate of mass transfer in the absorbers. These investigations concluded that bioscrubbers are not as effective as biofilters in treating hydrophobic compounds. However Hecht et al[23] used a bubble column bioscrubber to treat trichloroethylene (TCE), a highly volatile and moderately soluble compound. The bubble column was equipped with an aerator inside the bioreactor, providing a high ratio of liquid –to-gas volume. Experimental results revealed that 80%removal was achieved regardless of the TCE load, and that the process was limited by reaction rate rather than mass transfer rate of TCE. As a result, slight modification of bioscrubbers, or enhanced biochemical reactions in the liquid film, may be capable of compensating for the mass transfer rate of poorly soluble compounds.

## ECONOMIC EVALUATION OF BIO FILTRATION TECHNOLOGY

The market for air pollution control technologies comes both from the need for VOC control in urban air areas and from the developing need for control of hazardous and toxic air pollutants. Bio filtration can occupy an increasing share of the market as its economic and increasing share of the market as its economic and operational advantages are demonstrated with more installations. In this section a general re-view is made to give insight into the market trend of bio filtration and to establish the operational factors that determine the overall cost of a bio filter.

**1. Market Trend for Biofiltration:** According to yudelson[24] the potential market for biofiltration will reach approximately 5.5 billion dollars by year 2000. Among the three major segments, which include air pollution control odor control and remediation systems the remediation segments which include air pollution control, odor control and remediation system the remediation segment will occupy nearly 40% of the market (up from 20% in 1994). Currently a number of technologies are available for controlling VOC emissions from soil vapor extraction (SVE) and air stripping of contaminated ground water and soil. The most commonly used technologies include carbon adsorption and catalytic/ thermal oxidation. From the clients perspective of course the most desirable method to be selected is the one that would meet regulatory obligations at the least possible cost with consistent safety and reliability during operation. The flexibility of the method its initial and total project costs, as well as its adaptability with other existing processes are also considered as the selection criteria.

**2. Factors Influencing Bio filtration Cost:** Since bio filtration is still being considered as an emerging technology for odor control and VOCs removal, its comparison to other state-of –the-art technologies from an accurate economic perspective would be unrealistic due to limited available information. As a result, the existing cost analysis may be less reliable until the bio filter market and technical sophistication reach a mature stage. Nevertheless, a number of reports have been published to estimate the capital and operational costs of bio filters based on the design criteria. Some of the major factors that determine the economical competitiveness of bio filtration are discussed below[27, 1].

**2.1. Elimination Rate:** Elimination rates for non chlorinated organic pollutants vary widely depending on the water solubility, bio degradability, and influent concentration. Generally, elimination rates ranging between 10 and 100 $g/m^3/h$ may be achievable for moderately and highly bio degradable compounds. The higher the elimination rate, the lower the required filter volume; consequently, the lower capital cost for a bio filter.

**2.2. Pollutant concentration**: As a rule-of –thumb, bio filters are most suitable for treating air streams with diluted concentration not exceeding 1 $g/m^3$ (or 500 ppmv) of total carbon. Above this concentration, energy efficient incineration technologies become increasingly competitive due to the reduced amount of supplementary fuel needed, unless high removal rate can be obtained by bio filtration,

**2.3. Air (off-gas) flow rate**:_The air flow rate determines the dimension of the filter bed required. Units designed for flow rates less than 17,000 $m^3$/h can be installed on roof-top. Generally, vendor-installed cost of bio filters can be directly estimated from air flow rate at approximately $34 per $m^3$ /h. Typical operating cost is expected to be $12 per $m^3$ /h per year.

**2.4. Raw condition of waste gas**:_The physical and chemical conditions of the raw gas can significantly alter the design constraint. For instance, waste streams with high temperature and high particulate concentration may require pretreatment prior to entering the bio filters. Additionally, presence of acid-forming pollutants can shorten the bio filter's life –span.

**2.5. Site specific criteria**: Availability of space and local building codes, in particular for roof- top installation, can have significant impact on capital cost.

**3. Capital cost:** Van Lith et al.[25] recently established an estimated range of capital cost for bio filters than 100 $m^3$ installed in the North America since 1990. The capital costs are compared on a per-volume basis rather than a performance basis. The range of cost-per-volume tends to be narrower as the bio filter volume becomes larger. Open systems place at the low end on the per-volume basis, with enclosed and controlled multi-level bio filter at the high end. Enclosed concrete vessels with a 1.5-m bed height fall in between. A major capital cost indicator is the gas residence time in the bio filter.

Total cost per volume is significantly lower for residence time of 15 seconds than it is at 60 seconds, particularly at flow rates less than 50,000$m^3$ /h. therefore, although open system ranks at the low end of installation cost, lack of control and optimization usually requires a longer residence time; and correspondingly, a higher cost per volume.

**4. Operating and Maintenance Costs:** Operating cost involves energy and water consumption, media replacements and maintenance. Energy consumption is mainly due to waste gas transport through ducts humidifier and filter beds. Pressure drop across filter beds may be a major source of energy consumption. Therefore, media selection is critical for open and multilevel bio filters to avoid pressure build-up. Water consumption for open bio filters differs substantially depending on the rate of preparation and evaporation in local areas. Biotrickling filters and bio scrubbers, due to their operational modes, require larger water consumption and treatment cost than the conventional bio filters. Media replacement is required when the pressure drop becomes unacceptably high. A well engineered bio filter usually employs processed or synthetic media and routinely achieves bed lives of more than five year without significant deterioration. Open bio-filters are normally packed with inexpensive and less processed media, however the lower media cost may be partially offset by the shorter useful life of the media. Maintenance costs include labour for control and monitoring of proper bio-filter operating conditions, as well as the necessary inspection and repair works.

## MECHANISMS

The biodegradation of pollutants in the biofilm of a biofiltration system is a combination of physicochemical and biological phenomena. Basically following three mechanisms are responsible for the transfer and subsequent biodegradation within the bed[26, 1, 28] **Figure-1.**

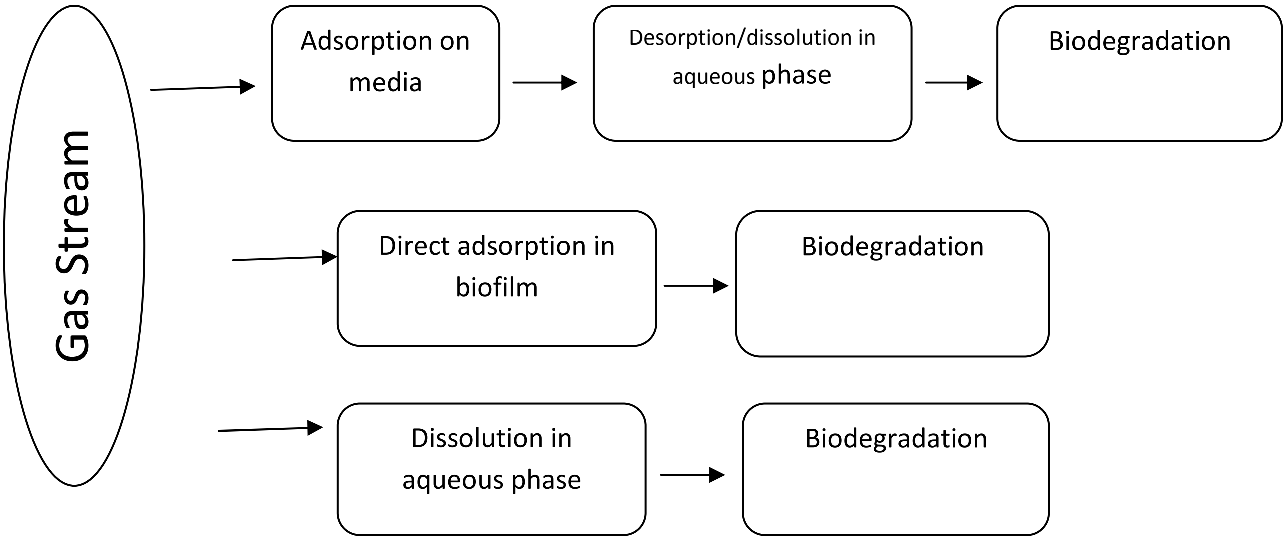


**Figure-1: Mechanism of biofiltration**

Once the pollutants are adsorbed on the biofilm or dissolved in the water layer surrounding the biofilm, the contaminants are available to the microorganisms as a food source to support the microbial life and growth. Air that is free, or nearly free, of contaminants is then exhausted from the biofilter. **Figure-2** shows the mechanism of mass transfer occurring during biofilter process. As the gas stream passes through the packing, contaminants are transferred from the gas stream to the water in the biofilm**.**

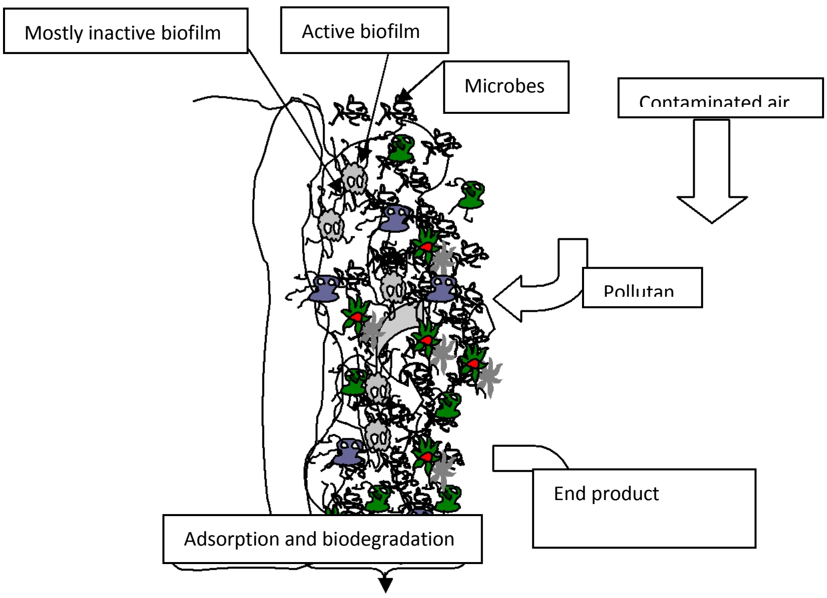


**Figure -2: Phenomena involved in the operation of biofilters**

A number of researchers have worked on the measurement of concentration of contaminants by GC-FID[29]. The contaminants diffuse into the depth of the biofilm, where they are adsorbed` by the microorganisms in the biofilm and biodegraded. Contaminants may also be adsorbed at the surface of the packing. The greater majority of reactors utilize aerobic respiration, so that oxygen and must also be dissolved in the water or biofilm and degraded by the microorganisms. During operation at moderate-to-high concentration of contaminant, the biofilm will gradually grow thicker. At some point, diffusion will no longer provide all the needed compounds to the deeper portions of the biofilm, and microorganisms will become inactive. Because the pores within the packing are highly irregular in shape, the growing biofilm will change the pore size distribution.

## MECHANISMS IN BIOFILTER OPERATION

There are various transport mechanisms which operate simultaneously or sequentially in a biotrickling filter and these mechanisms, include: (1) diffusion of the contaminant(s) from the bulk gas flow to the active biofilm surface; (2) sorption of the contaminants directly on the biofilm surface; (3) solubilisation of the contaminant(s) into the water content of he biofilms; (4) direct adsorption of the contaminant(s) on the surface of the support media; (5) diffusion and biodegradation of the contaminant(s) in the active biofilm; (6) surface diffusion of the contaminant(s) in the support media surface; and (7) back diffusion of the adsorbed contaminant(s) from the support media surface into the active biofilms. The effect of adsorption of contaminant(s) on support media surface, surface diffusion, and back diffusion of the adsorbed contaminant(s) from the support media surface into the active biofilms, predominantly occurs in activated carbon-coated support media and contaminant(s) which have affinity for the support media surface.
In the case of compost biofilters the contaminant(s) diffuse into the porous compost particles, dissolve into the sorbed water films, adsorb on the organic and inorganic fraction of the compost, and biodegrade by the attached active compost bacteria, entrapped within the compost particles.

## CONCLUSION

Biofiltration will play a major role in the treatment of organic and inorganic emissions from a variety of industrial and waste water treatment processes. Biofiltration, when compared to other available technologies, has significant technical and cost advantages. The applicability of the three types of the biofilters (i.e., conventional biofilter, biotrickling filter and bioscrubber) depends to a large extent on the waste gas characteristics such as its solubility, biodegradability and the potential formation of acidic intermediates products. Compost biofilters are better suited for treatment of odors and low concentration (< 25 ppmv) contaminants. Biotrickling filters have significant advantages over compost biofilters and are capable of handling significantly higher contaminant concentrations (20 ppmv – 5,000 ppmv). The major issues in biotrickling filters are the design of the support media and handling of biomass growth. Support media design has a significant impact on biotrickling filter performance. The market for biofilters will increase in the next millennium, as new applications arise in the future.

## REFERENCES

1. S. Dharmavaram; Biofiltration: A Lean Emissions Abatement Technology. *Proceeding of the 84$^{th}$ Annual meeting of the Air & Waste Management Association*, Vancouver, British Colombia; 1991.
2. S.J. Ergas; Control of Low Concentration Volatile Organic Compound Emissions Using Biofiltration (Public Owned Treatment Works). *Ph.D. Dissertation, Department of Civil Engineering, University of California, Davis*; 1993.
3. R. A. Zurlinden; Treatment of Volatile Organic Compounds in a Pilot Scale Biofilter. *Proceeding of the 86$^{th}$ Annual Meeting of the Air &Waste Management*; 1993.
4. K. H. Man; An Evaluation of Packing Media for the Biofiltration of Methylene Chloride and Methanol Vapors. *Master Thesis, Department of Civil Engineering University of Southern California, Los Angeles, CA*; 1995.
5. V. F. Medina; Development of Biological Filters Using Granular Activated Carbon as the Gasoline Vapors. *Ph.D. Dissertation, Department of Civil Engineering, University o Southern California, Los Angeles, CA*; 1992.

6. V. F. Medina, T. Webster, M. Ramaratnam, and J. S. Devinny; Treatment of Gasoline Residuals by Granular Activated Carbon Based Biological Filtration. *J. Environ. Sci. Health*; 1995, A30(2), 407-422.
7. F. J. Weber, and S. Hartmans; Use of Activated Carbon as a Buffer in Biofiltration of Waste Gases with Fluctuating Concentrations of Toluene. *Appl. Microbial. Biotechnol*; 1995, 43(2), 365-369.
8. F. A. Craveiro de Sa, and J. F. Malina; Bioregeneration of Granular Activated Carbon. *Wat.Sci Technol;* 1992, 26(9-11), 2293-2295.
9. T. O. Williams, and F. C. Miller; Odor Control Using Biofilters. Part I. *Biocycle*; 1992, 33(10), 72-77.
10. H. F. Ockeloen, T. J. Overcamp, and C. P. L. Grady, Jr; A Biological Fixed-Film Simulation Model for the Removal of Volatile Organic Air Pollutants. *Proceeding of the 85$^{th}$ Annual Meeting of the Air & Waste Management Association, Kansas City, Missouri*; 1992.
11. T. J. Overcamp, G. R. DeHollander, H. C. Chang, and C. P. L. Grady, Jr; A Biologically Enhanced Scrubber for Volatile Organic Compounds. *Proceeding of the 84$^{th}$ Annual Meeting of the Air & Waste Management Association, Vancouver, British Colombia*; 1991.
12. L. E. Reutlinger; Design and Operation of a Biological Fix-film Scrubber for Removal of Hydrogen Sulfide Gas. *Master Thesis, State University of New York*; 1994.
13. V. P. Utgikar; Fundamental Studies on the Biodegradation of Volatile Organic Chemicals in a Biofilter. *Ph.D. Dissertation, Department of Chemical Engineering, University of Cincinnati, Cincinnati;* 1993.
14. R. M. M. Diks, and S. P. P. Ottengraf; Verification Studies of A Simplified Model for the Removal of Dichloromethane from Waste Gases Using a Biological Trickling Filter (Part II). *Bioproc. Enr*; 1991, 6(4), 131-140.
15. S. Hartmans, and J. Tramper; Dichloromethane Removal from Waste Gases with A Trickling-Bed Bioreactor. *Bioproc. Engr*; 1991, 6(2), 83-92.
16. A. P. Tonga, and B. R. Folsom; Removal of Styrene from Air Using Bench-Scale Biotrickling Filter Rectors. *Proceeding of the 85$^{th}$ Annual Meeting of the Air &Waste Management Association, Kansas City, Missouri; 1*992.
17. A. P. Tonga, and M. Singh; Biological Vapor-Phase Treatment Using Biofilter and Biotrickling Filter Reactors: Practical Operating Regimes. *Envion. Progr*; 1994, 13(2), 94-97.
18. R. M. M. Diks; The Removal of Dichloromethane from Waste Gases in a Biological Trickling Filter. *Ph.D. Dessertation, Department of Chemical Engineering, Technische Universiteit Eindhoven, The Netherlands*; 1992.
19. R. M. M. Diks, and S. P. P. Ottengraf; Verification Studies of A Simplified Model for the Removal of Dichloromethane from Waste Gases Using a Biological Trickling Filter (Part I). *Biopro. Engr*; 1991, 6(3), 93-99.
20. B. E. Rittmann, and P. L. McCarty; Utilization of Dichloromethane by Suspended and Fixed-Film Bacteria. *Appl. Envion. Microbial*; 1980, 39(6), 1225-1226.
21. T. J. Overcamp, H. C. Chang, and C.P. L. Grady, Jr; An Integrated Theory for Suspended Growth Bioscrubbers. *J.Air & Waste Manage. Assoc;* 1993, 43(5), 753-759.
22. S. P. P. Ottengraf, J. J. P. Meesters, A. H. C. van den Oever, and A.H. C. Rozema; Biological Elimination of Volatile Xenobiotic Compounds in Biofilters. *Bioproc. Engr;* 1986, 1(1), 61-69.
23. V. Hecht, D. Brebbermann, P. Bremer, and W. D. Dechwer; Cometabolic Degradation of Trichloroethylene in A Bubble Column Bioscrubber. *Biotechnol. Bioeng;* 1995, 47(4), 461-469.
24. J.M. Yudelson; The Future of the U.S. Biofiltration Industry. *Proceeding of the 1996 Conference on Biofiltration, Los Angeles, California*; 1996.
25. C. Van Lith, G. Leson, and R. Michelson; Evaluating Design Options for Biofilters. *J. Air & Waste Manage. Assoc;* 1997, 47(1), pp.37-48.
26. S. P. P. Ottengraf and A H.C. van den Oever; Kinetics of Organic Compound Removal from Waste Gases with a Biological Filter. *Biotechnol. Bioengg;* 1983, 25(12), 3089-3102.

27. G.Leson, F. Tabatabal, and A. M. Winer; Control of Hazardous and Toxic Air Emissions by Biofiltration. *Proceeding of the 85th Annual Meeting of the Air & Waste Management Association, Kansas City, Missouri*; 1992.

28. H. M.Tang, S. J. Hwang, and S.C. Hwang; Dynamics of Toluene Degradation in Biofilters. *Haz. Waste & Haz. Mat;* 1995, 12(3), 207-219.

29. R. D. Pomeroy; Controlling Sewage Plant Odors. *Consulting Engr;* 1963, 20(1), 101.

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