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Biofiltration: A method for Volatile organic compounds(VOCs) removal-A review

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***Abstract* - Due to increase in air pollution these days the discharge standards of air pollutants have been strictly stipulated. The slow removal of air pollutants like VOCs which tend to accumulate in the environment has led to the development of new sophisticated technologies in which biofiltration is emerging as a cheap and feasible biological treatment technology. The biofiltration produces no harmful end product and is easy to operate and maintain. The current paper compares various air pollutants removing technologies and discusses various factors affecting biofiltration process.**

***keywords* - Biofiltration, Vocs(Volatile Organic Compound),biofilter,btex(Benzene,toulene,ethylbenzene,xylene),air Pollution**

Introduction

Over the past decades significant amounts of pollutants from various industrial sourceshave been released into the atmosphere. There has been an increase in a variety of problems like smog formation, acid rain, odour nuisance, greenhouse effect and health impactsdue to highrelease of air pollutants. These xenobiotic compounds are removed slowly and have tendency to accumulate in the environment.With growing public awareness in health aspects and environmental impact, strict rulesare being enforced on the industries to restrain the air pollutants. There are different technologies to control the volatile organic compounds (VOCs) emission, but these are not applicable everywhere. Table 1 compares the various availabletechnologies to control VOCs emission. All technologies are applicable depending upon the type, source and concentration of the VOCs. The traditional VOCs removal techniques such as adsorption, absorption, condensation, thermal incinerationand some recent methods such as electronic coagulation, membrane separationare very efficientbut they produce unwanted byproducts. These are expensive and energy intensive techniques for the treatment of polluted air stream. Compare to these techniques biological treatment is an attractive option for low concentration gas streams because it requires low energy consumption,moderate operating cost and minimum by-product generation.There are different biological treatment methods which include biofilters, membrane bioreactors, bio-trickling filters and bioscrubbers. The basic pollutant removal technique of all the treatments is more or less similar, difference exists in the use of micro-organisms(may be either suspended in liquid) or immobilized(biofilm form), packing media and pollutant concentration(Sandeep Mundaliar et al.,2010).

Biofilters were invented for removal of odor in Europe. Over the past two decades Biofilters have been transformed from an odor removing system to a controlled and technically viable unit for removing odor as well as specific chemicals from industrial operations.In biofiltration process microbial attack occurs on the contaminants which are sorbed from the gas to the aqueous phase. During microbial attack microorganismsconvert contaminants into CO_2, water vapour and organic biomass bythe oxidation process which can be written as

$$VOC + O_2 \longrightarrow CO_2 + H_2O + Heat + Biomass \qquad \text{(Zilli et al., 2005)}$$

Table-1 Current technologies for air pollution control

Methods (conventional and upcoming)	Technology involved	Operational characteristics			Advantages	Disadvantages
		Gas flow (m^3h^{-1})	VOC (gm^{-3})	Temperature °C		
Adsorption	Activated carbons, Zeolites	5-50000	<10	<55	Proven and Efficient	Adsorption is too specific and can saturate fast; Risk of pollutant reemission
Absorption	Washing gas with contaminated water	100-60000	8-50	Normal	Possible recovery of VOC	Not suitable for low concentrations, generates wastewater

Incineration	Thermal oxidation	>10000	2- 90	371	Efficient	Not cost effective, Incomplete mineralization and release of secondary pollutants.
Condensation	Liquefaction by cooling or compression	100- 10000	>60	Ambient	Possible recovery of VOC	Further treatment is required, Applicable in high concentrations only
Filtration	Air passed through fibrous material coated with viscous materials	100- 10000	>60	10-41	Efficient for particle removal, compact and commonly used	Unable to remove gases, fouling, particle reemission can occur due to microbial growth
Membrane separation	Separation through semipermeable membrane	5-100	>50	Ambient	Recommended for highly loaded streams	Membrane fouling and high pressure is indeed
Catalytic oxidation	Thermal catalysts(Pt,Al,ceramics)	>10000	2-90	149	Efficient, conserves energy	Catalyst deactivation and its disposal, formation of by-product
Electrostatic precipitator with ionization	Electric field is generated to trap charged particles	-	-	-	Efficiently removes particle and are compact	Generate hazardous by-products
Enzymatic oxidation	Use of enzymes for treatment of air pollutants	-	-	35-55	Promising	Requirement of new enzymes periodically
Phytoremediation	Use of plants and microbes for the removal of contaminants	-	-	-	Cost effective, pollution free and complete mineralization occurs	Large as compared to other technologies
Photo catalysis	High energy UV radiation used along with a photo catalyst	-	-	-	Energy intensive popular method suitable for broad range of organic pollutants	Exposure to UV radiation may be harmful
Microbial abatement	Air passed through a packed bed colonized by attached microbes as biotrickling filters or microbial cultures in bioscrubbers	200- 1500	<5	-	Cost effective, more efficient, eco-friendly	Need for control of biological parameters
Ozonation	Strong oxidizing agent	-	-	-	Removes fumes and gaseous pollutants	Generate unhealthy ozone and degradation products
Photolysis	UV radiations to oxidize air pollutants and kill pathogens	-	-	Normal	Removes fumes and gaseous pollutants	Release of toxic photoproducts, UV exposure may be

						hazardous and energy consuming

Table -2 Comparison of Bioreactors for VOC and odour control

Bioreactors	Application	Advantages	Disadvantage
Biofilter	• Removal of odour and low VOCs Concentrations • Target VOC concentration is less than 1 gm^{-3}	• Low initial investment and subsequently operating cost is minimized • Degrades a wide range ofcomponents • Easy to operate and maintain • No unnecessary waste streams are produced • Low pressure drop • Possibility of different microorganisms, media and operating conditions for many emission points.	• Less treatment efficiency at highconcentrations of pollutants • Extremely large size of bioreactorchallenges space constraints • Close control of operating conditions isrequired • Packing has a limited life • Clogging of the medium due to particulatemedium
Membrane bioreactor	• Medium/High VOCconcentrations • Target VOCconcentration is lessthan 10 g m-3	• No moving parts • Process easy to scale up • Flow of gas and liquid can bevaried independently, without theproblems of flooding, loading, orfoaming	• High construction costs • Long-term operational stability (needsinvestigation) • Possible clogging of the liquid channels duethe formation of excess biomass
Biotrickling filter	• Low / medium VOCconcentrations • Target VOCconcentration is less than 0.5 g m^{-3}	• Less operating and capital constraints • Less relation time / high volumethrough put • Capability to treat aciddegradation product of VOCs	• Accumulation of excess biomass in the filterbed • Requirement of design for fluctuatingconcentration • Complexity in construct and operation • Secondary waste stream
Bioscrubber	• Low/medium VOCconcentrations • Target VOCconcentration less than 5 g m^{-3}	• Able to deal with high flow rates and severe fluctuations • Operational stability and bettercontrol of operating parameters • Relatively low pressure drop • Relatively smaller space requirements	• Treats only water soluble compounds • Can be complicated to operate and maintain • Extra air supply may be needed • Excess sludge will require to disposal • Generation of liquid waste

Fundamentals of Biofiltration-

The Biofilter-

The Biofilter is a reactor in which contaminated gases pass through a fixed bed on which contaminant degrading microorganisms are immobilized. As the contaminated gas pass through the filter medium, the contaminants in the gas; transverse to the liquid phase surrounding the microbial biofilm in the medium where they are degraded to CO_2, H_2O, inorganic salts and biomass by microorganisms(Jorio et al., 2000; Deshusses, 1997). There are mainly two types of Biofilter configurations first, Open designed Biofilter second, Enclosed Designed Biofilter.The open systems, typically noted as soil filters, are the conventionaland the simplest type of biofilters(Figure 1). The waste gas is passes through a soil-compost pile pre-enriched with nutrients for microbial growth. The indigenous microorganisms present in the compost lead to the biodegradation of malodorous compounds present in the waste gas. As these systems are installed in open natural conditions they're exposed to weather fluctuations like rain, humidity, temperature etc.(Bajpai et al., 1999).

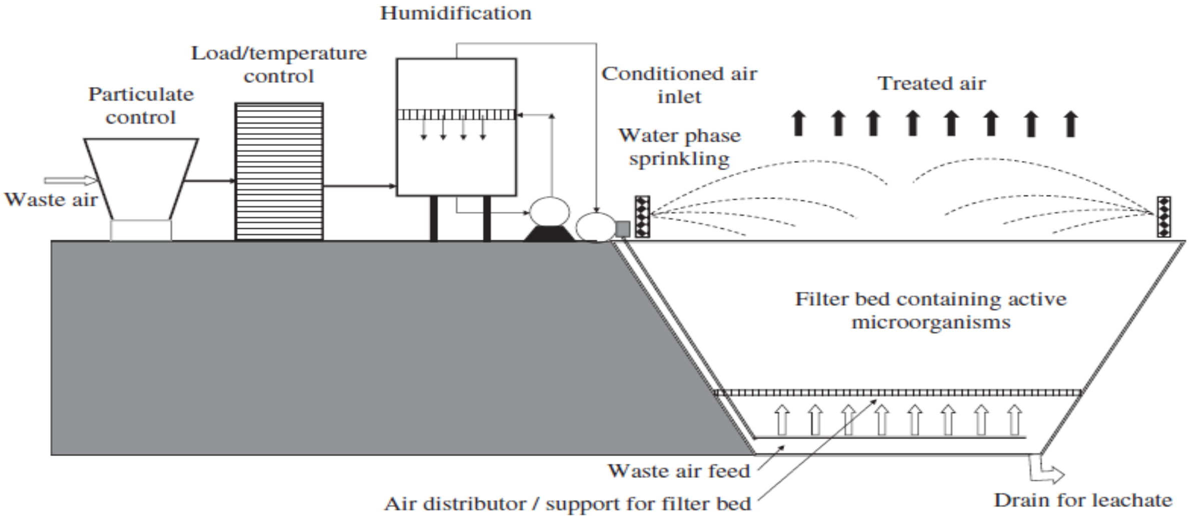

Figure 1 schematic diagram of an open designed Biofilter

The close type biofilters have one or more treatment beds or disks of different packing materials or media, nutrients, microbial cultures and/or compost in its reactor cell (Bajpai et al., 1999; Shareefdeen et al., 1993). Figure 2 shows the schematic diagram of closed designed Biofilter. As the waste gas pass through the Biofilter the bed humidifies it and allows its components to undergo degradation by the microorganisms. The water if condensed during the process is returned to the humidification system for reuse. TheseBiofilters having working area up to 6000 square meters can filter up to 3000 m3/min of waste air (Bajpai et al., 1999).

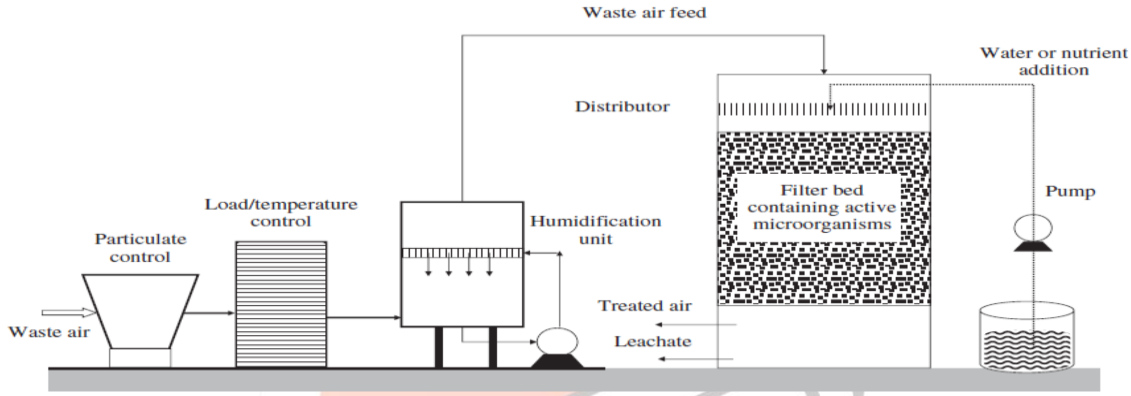

Figure 2 Schematic diagram of a closed designed Biofilter

Mechanisms of Biofiltration

The principles governing biofiltration are similar to those of common biofilm processes. Basically a three-step process occurs within the bed of Biofilter. First, a chemical in the gaseous phase crosses the interface between gas flowing in the pore space and the aqueous biofilm surrounding the solid medium. Thenthe chemical diffuses through the biofilm to a consortium of acclimated microorganisms. Finally, the microorganisms obtain energy from oxidation of the chemicals as a primary substrate, or they co-metabolize the chemical via nonspecific enzymes. Simultaneously, there is diffusion and uptake of nutrients such as nitrogen and phosphorous in available formsand oxygen within the biofilm. Utilization of the chemicals,electron acceptors, and nutrients continuously maintains the concentration gradients driving diffusive transport in the biofilm. A properly designed and operated biofilter converts target waste gas chemicals to end products such as CO_2, H_2O, inorganic salts and biomass.

Parameters affecting Biofiltration

1. **Biofilter bed**

   It represents the heart of biofiltration because it provides support for growth of microorganisms. It should have high porosity, high specific surface area for microbial growth and good water retention capacity. Peat, composts, soils and wooden chips are mainly used bed material because they are cheap, easily available and satisfy most of the required criteria for bed material. Peat represents high specific surface area, contains high amounts of organic matter and good water holding capacity. But the nutrient content and microbial content are less in the peat. Composts are most frequently used packing material in biofiltration because it provides sufficient inorganic nutrients for microbial growth and addition of nutrients are not required. Compostsare less stable than peat or soil and have tendency to collapse and compact, leading to increase in pressure drop in Biofilter bed. The main advantage of soil as a Biofilter bed is that it has rich and varied microflora but gives low specific surface area and generates high pressure drops. Some authors have studied wooden chips or barks as Biofilter bed (Smet et al., 1996; Smet et al., 1999; Hong and Park, 2004) but they have shown that using soil or bark as bed material gives less satisfactory performance as compare to peat, soils and composts. Between initial and final day of experiment the microbial growth on the packing media surface in various segments of biofiltration can be observed by using scanning electron microscopy.

2. **Temperature**

Temperature is one of thefactors that affect the performance of Biofilter because intensity of microbial activity depends on operating temperature. The optimum temperature ranges between 20°C to 30°C. But most of the microorganismsthat develop in the media are mesophilic in nature which implies that temperature ranging between 30°C to 40°C is conducive for their growth and activities. In some cases the biodegradation process increases with increase in temperature. But temperature should be controlled below 40°C with proper care or otherwise decay of microbial population takes place.

3. pH

As for many aerobic biological processes, optimum pH for biofiltration process ranges between 7and 8, for growth ofbacteria and 2-7 for growth of Fungi. In some cases biodegradation of chemicals results in acidic end products such as in case of oxidation of nitrogen or sulphur containing compounds. In such cases due to drop in pH, microbial population decreases and leads to reduction in filter's degradation capacity. To prevent these types of situations chemical buffers such as limestone, crushed oyster shells and marl are added during Biofilter medium preparation in sufficient stoichiometric equivalents to buffer that acid formation over the design life.

4. Moisture content

Moisture content in the filter bed plays an important role in the performance of Biofilter because moisture is essential to carry out metabolic activity of the microorganism in the biofilm. Too low bed moisture content can result into the reduction of biodegradation rate. On the other hand too high bed moisture content can block the oxygen and hydrophilic pollutants transfer to the biofilmwhich leads to the development of anaerobic zones within the bed. For optimum operation of Biofilter, moisture content should be within 40-60% by weight, depending upon the type of filter medium. In Biofilters, moisture content is maintained by pre-humidification of inlet gas stream.

5. Microorganisms

Microorganisms are considered as main catalyst for degradation of air pollutants in the Biofilter. Bacteria and fungi are the predominant heterotrophic microorganisms involved in the biodegradation. Heterotrophic microorganisms are those who use organic off-gas constituents as carbon and energy source for their growth and metabolic activities. After an acclimation time, the most resistant microorganism population is naturally selected and a microbial hierarchy is developed in the filter bed. Higher density of microorganism will develop near the influent end and smaller population of microorganism will develop at deeper point of the bed. In terms of biomass density, a Biofilter usually contains 10_6 to 10_{10} CFU(colony forming unit) of bacteria and some 10_3 to 10_6 CFU of fungi per gram of bed. The degrading species ranges between 1-15% of total population of microorganism. Table 3 show some of strains used in biofiltration, either as inoculums or as material isolated from the operation.

TABLE 3 Microorganisms identified during the degradation of VOC by biofiltration

Pollutants	Microorganisms	Reference
Benzene	*Pseudomonas sp.* *Alcaligenes xylosoxidans* *Cladosporium sphaeraspermum,* *Exophiala lecanii-corni,* *Phanerochaete chrysosporium*	Sene et al., 2002 Yeom and Daugulis, 2001 Qi et al., 2002
BTX(benzene toluene xylene)	*Phanerochaete chrysosporium*	Oh *et al.*, 1998
Butylacetate	*Cladosporium resinae,* *C.sphaeraspermum,* *Exophiala lecanii-corni,* *Mucor rouxi,* *Phanerochaete chrysosporium*	Qi *et al.*, 2002
Chlorobenzene	*Pseudomonas sp.*	Seignez *et al.*, 2001
Dichloromethane	*Pseudomonas putida* *Hyphomicrobium sp.*	Ergas *et al.*, 1996 Diks et al., 1994
Dimethyl sulfide	*Hyphomicrobium*	Smet *et al.*, 1999
Ethanol	*Candida utilis*	Christen *et al.*, 2002
Ethylacetate	*Rhodococcus fascians*	Hwang *et al.*, 2002
Ethylbenzene	*Cladosporium resinae,* *C. sphaeraspermum,* *Exophiala lecanii-corni,* *Phanerochaete chrysosporium*	Qi *et al.*, 2002
Ethylene	*Mycobacterium sp.*	Deheyder *et al.*, 1997

Methylethylketone	*Alcaligenes denitrificans, Geotrichum candidum, Fusiarum oxysporum*	Agathos *et al.*, 1997
	Cladosporium resinae, C. sphaeraspermum, Exophiala lecanii-corni	Qi et al., 2002
	Rhodococcus sp.	Amanullah et al., 2000
Methylisobutylketone	*Cladosporium resinae, C. sphaeraspermum, Exophiala lecanii-corni, Phanerochaete chrysosporium*	Qi *et al.*, 2002
Methyl-tertbutyl-ether	*Pseudomonas aeruginosa*	Dupasquier *et al.*, 2002
Pentane	*Pseudomonas aeruginosa*	Dupasquier *et al.*, 2002
Phenol	*Pseudomonas putida*	Zilli *et al.*, 1996
α-pinene	*Aspergillus sp.*	Diehl *et al.*, 2000
	Pseudomonas fluorescens, Alcaligenes xylosoxidans	Kleinheinz et al., 1999
Styrene	*C. sphaeraspermum, Exophiala lecanii-corni*	Qi *et al.*, 2002
	Tsukamurella, Pseudomonas, Sphingomonas, Xanthomonas	Arnold et al., 1997
	Exophiala jeanselmei	Cox et al., 1997
TEX+	*Bacillus sp., Pseudomonas sp., Trichosporon beigelei*	Veiga *et al.*, 1999
Toluene	*Acetinobacter sp.*	Marek *et al.*, 1999
	Pseudomonas putida	Park *et al.*, 2002; Ergas *et al.*, 1996; Villaverde and Fernandez, 1997
	Pseudomonas pseudoalcaligenes	Oh and Choi, 2000
	Exophiala lecanii-corni	Woertz *et al.*, 2001
	Scedosporium apiospermum	Garcia-Pena *et al.*, 2001
	Corynebacterium jeikeium, C. nitrilophilus, Turicella oritidis, Pseudomonas mendocina, Sphingobacterium thalphophilum, Micrococcus lutens	Strauss et al., 2000
	Cladophalophoria sp.	Woertz et al., 2002
Trichloroethane	*Pseudomonas putida*	Ergas *et al.*, 1993
Trichloroethylene	*Pseudomonas putida*	Cox *et al.*, 1998; Ergas *et al.*, 1993
Xylene	*Pseudomonas pseudoalcaligenes*	Oh and Choi, 2000

6. Nutrients

Microorganisms established in the Biofilter bed are essentially composed of oxygen, carbon, hydrogen, sulphur, nitrogen and phosphorus. Oxygen and hydrogen are found in the growth medium, in the air and sometimes in the VOC. The availability of macro-nutrients (N, K, P and S) and micro-nutrients (metals and vitamins) depend upon both the Biofilter configuration and characteristics of bed material. From the literature it has been confirmed that regardless of the bed material used, steady addition of nutrients is vital to withstand degradation activity by the microorganisms. The problem of nutrient addition and its availability is important in biofiltration process, yet there are no recommendations presently developed which decide the amount of available nutrients required in Biofilter.Nutrients are supplied either as solid by direct insertion into filter bed, or as mineral salts dissolved in aqueous solution, which is most frequently used method. The most commonly used nutrient solutions are KH_2PO_4, NH_4Cl, $CaCl_2$, NH_4HCO_3, $MgSO_4$, KNO_3, $(NH_4)_2SO_4$, $FeSO_4$, $MnSO_4$, $Na_xH_{(3-x)}PO_4$, Na_2MoO_4 and vitamins(B1, B2, etc.).

7. Air Flow rate and EBRT

Air flow rate and empty bed residence time are the parameterswhich can affect the performance of Biofilter. By increasing the air flow rate the rate of biodegradation of the pollutants decreases because in extremely high air flow rate, the contact time between contaminated gases and microorganisms (residence time) are too short and biodegradation of the contaminated gases can't be completed. But if air flow rate is low then the residence time becomes higher. Most of the research shows that the longer EBRT give rise to better biodegradation of pollutants. Thus EBRT should be greater than the air flow rate for the improvement in Biofilter performance. A typical Biofilter requires an air flow rate of 0.055m^3h^{-1} per m^2 of surface area and EBRT of 15 seconds to several minutes.

Conclusion

The slow removal of BTEX and their accumulation in the environment is becoming notorious part of air pollution these days. This problem led to the development of a new biological treatment method; biofiltration process, which is cheaper than other technologies and has minimum end products. In biofiltration process microbial attack occurs on the contaminants which are sorbed from the gas to the aqueous phase. During microbial attack microorganisms convert contaminants into CO_2, water vapour and organic biomass by the oxidation process. The main factors affecting biofiltration process are pH, bed material, nutrients available, moisture content, temperature and air flow rate and EBRT. From the literature surveyit was concluded that many bacteria especially *pseudomonas* species are widely used in biodegradation of the BTEX.

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