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Review Research Paper

Biofilters in Mitigation of Odour Pollution - A Review

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ABSTRACT

Odour is one of the most complex problems of all the air pollution problems. Undesirable odours contribute to air quality concerns that affect human lifestyles and are considered a nuisance to the general public. This study presents the role of biofilters for the control of volatile organic compounds (VOCs) and other odorous substances. Biofilters absorb the odorous and noxious gases into a biofilm where it is biodegraded by microorganisms into simpler and less toxic compounds like carbon dioxide, water and salts and use the energy and nutrients to grow and reproduce. About 95 percent of hydrogen sulfide (H_2S) and 80 percent of ammonia (NH_3) can be reduced by a well designed and managed biofilter. The mechanism of biofiltration depends on different factors viz., inlet gas concentration, empty bed residence time, bed height, type of media and these factors has a direct effect on the removal efficiency of a biofilter. Biofiltration, which has the ability to treat a broad spectrum of gaseous compounds has been regarded as a promising odour and gas treatment technology that is gaining acceptance in a number of industries and factories, being not only cost effective as compared to conventional techniques but are also environmental friendly.

INTRODUCTION

Pollution is one of the serious issues the world is facing today. Since the industrial revolution, the problem of pollution has got aggravated due to tremendous progressions in industries, transportation, urbanization and global agriculture. With respect to air pollution, undesirable odour is a major concern in the present day era because of its malodorous property and is considered a big nuisance to the general public. Odour is defined as a physiological stimulus of olfactory cells in the presence of specific molecules that varies between individuals and with environmental conditions such as temperature, pressure and humidity (Rappert & Muller 2005).

Odour is often a complaint in urban areas which are associated with the waste gas emissions. Important sources of odorous gas emissions are industries, food processing industries, dairy industries, pharmaceutical industries, rubber processing plants, pulp and paper industries, textile industries, petroleum refineries, paint finishing plants, chemical industries, livestock production houses, composting plants, wastewater treatment facilities, as well as solid waste dumping sites (Rappert & Muller 2005). Various odour emission sources are shown in Table 1. More than 100 kinds of odorous gases are emitted from different processing and manufacturing units, of which the sulphur and nitrogen-containing compounds and short-chain fatty acids have gained much attention due to their low threshold limits (Chung et al. 2007). Table 2 presents some of these compounds along with information about their offensive odours and odour threshold. Undesirab12.1 the treatment process but also give insights to develop newer, better and robust treatment techniques.

The objective of this review is to provide an overview about the role of biofilters in control of VOCs and odours and some important operational parameters of biofilters that directly affect the efficiency of the biofilters.

Biofilters: Biofilters are reactors in which waste gases are allowed to pass through a porous packed bed material immobilized with suitable microbial cultures that degrade the pollutants absorbed on to them (Chen & Hoff 2011). As the waste gas passes 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, Chen & Hoff 2011). In a biofilter the waste gas is passed through a medium pre-enriched with nutrients for microbial growth. The indigenous or added microorganisms present in the compost leads to the biodegradation of malodorous compounds present in waste gas (Shareefdeen et al. 2011). Biofilters are used to treat air from mechanically ventilated buildings that use fans to control airflow. They also can be used to treat air from a covered manure storage unit or other enclosed treatment facility (Janni et al. 2011, Chen & Hoff 2012). However, biofilters cannot treat air that exhausts from naturally ventilated barns through open sidewalls or ridges because the air cannot be collected and directed to a biofilter (Janni

Table 1: Various odour emission sources.

Scales of Odour	Odour Emission Sources	Odour Emission rate(OER) m^3/m	Distance of Influence (m)
Large	Pulp factory, Rendering plants, Fish meal plant, Rayon factory etc.	10^7-10^9	1000-5000
Middle	Poultry farms, night soils, wastewater treatment plants, coffee baking factory, car coating factory, metal coating factory, composting facility, rubber factory etc.	10^5-10^6	50-1000
Small	Restaurants, bakery, laundry, hair dresser, car repair shops, garbage collection shops, public lavoratory, septic tanks etc.	10^4 or less	5-500

(Source: Iwasaki 2004)

Table 2: Various types of odorous compounds.

Compound/odorant	Formula	Offensive odour	Odour threshold (ppb)
1. Inorganics			
Ammonia	NH_3	Pungent, Irritating	17
Chlorine	Cl_2	Pungent, Suffocation	0.08
Hydrogen sulphide	H_2S	Rotten eggs	0.0047
Ozone	O_3	Pungent, irritating	0.5
Sulphur dioxide	SO_2	Pungent, irritating	2.7
2. Acids			
Acetic acid	CH_3COOH	Vinegar	1.0
Butyric acid	$CH_3CH_2CH_2COOH$	Rancid butter	0.12
Propionic acid	CH_3CH_2COOH		0.028
3. Amines			
Methyl amine	CH_3NH_2	Putrid, Fishy	4.7
Ethyl amine	$C2H_5NH_2$	Ammonical	0.27
4. Mercaptans	CH_2CHCH_2SH	Disagreeable, garlic	0.0015
Allyl mercaptan			
Amyl mercaptan	$CH_3(CH_2)_4SH$	Unpleasant, Putrid	0.0003
Benzyl mercaptan	$C_6H_5CH_2SH$	Unpleasant, strong	0.0002
Ethyl mercaptan	C_2H_5SH	Decayed Cabbage	0.0003
Methyl mercaptan	CH_3SH	Rotten Cabbage	0.0005
5. Sulphids			
Diethyl sulphide	$(C_2H_5)_2S$	Ether	0.02
Dimethyl sulphide	$(CH_3)_2 S$	Decayed cabbage	0.001
Dimethyl disulphide	$(CH_3)_2S_2$	Putrid	0.028
6. Alcohols			
Amyl alcohol	$C_5H_{11}OH$	-	-
Butyl alcohol	$CH_3(CH_2)_3OH$	-	0.1
Phenol	C_6H_5OH		

(Source: Metcalf and Eddy, 2003; CPCB, 2008)

et al. 2011). A biofilter has different components (Janni et al. 2011).

- A mechanically ventilated space with biodegradable gas emissions.
- A fan to move the odorous exhaust air from the building through the duct, plenum and biofilter media.
- Ducts connecting the ventilated space and an air plenum that distributes the air to be treated evenly beneath the biofilter media.
- A porous structure to support the media above the air plenum.
- Porous biofilter media that serves as a surface for micro-organisms to live on a source of some nutrients.
- An irrigation system where moisture can be applied, retained and made available to the microorganisms.
- Two outlets, one placed at the top of a biofilter for the removal of treated air and a ground outlet used to collect the biodegradation end products. A typical biofilter is shown as in (Fig. 1).

History of biofilters: The brief history of biofilters is as under (Bellis 2007).

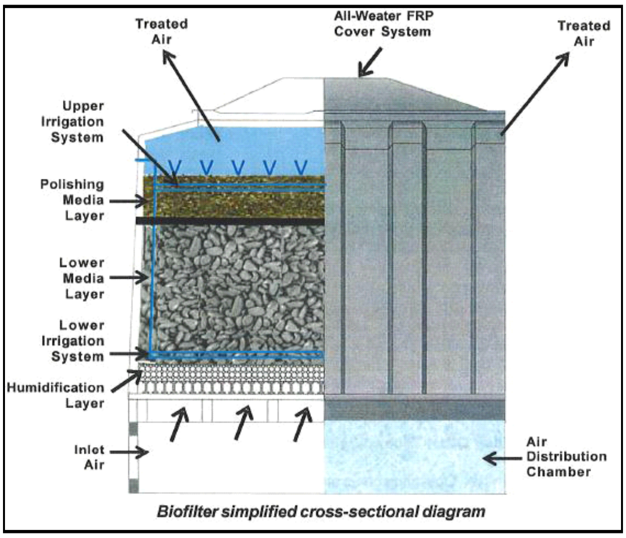
- **1923:** The first proposition to use biological methods to treat odorous compounds was as early as 1923. Biologically active biofilter was first used to control emissions of H_2S from a waste water treatment plant.
- **1955:** Biological methods were first applied to treat odorous emissions in low concentrations in Germany.
- **1959:** A soil bed was installed at a sewage treatment plant in Nuremberg for the control of odours from an incoming sewer main.
- **1960's:** Biofiltration was first used for the treatment of gaseous pollutants both in Germany and US and after that research was intensified.
- **1970's:** Biofiltration becomes widespread in Germany.
- **1980's:** Biofiltration is used for the treatment of toxic emissions and volatile organic compounds (VOCs) from industry.
- **1990's:** There were more than 500 biofilters operating both in Germany and Netherlands.

During the 1990s, biofilters were also used to remove airborne contaminants, including aliphatic and aromatic hydrocarbons, alcohols, aldehydes, organic acids, acrylate, carbolic acids, amines and ammonia. These substances are not just smelly, but are dangerous as well (Bellis 2007).

BIOFILTRATION PROCESSES

Biofiltration utilizes biologically active media to remove biodegradable VOC's, odors and other toxic compounds from the polluted air. Removal of contaminants follows a multistep process in which untreated air stream is passed though one or more beds of biologically active media, where these microorganisms biologically oxidize the pollutants into carbon dioxide and water. The treatment process relies on two fundamental mechanisms: diffusion and biodegradation. As contaminated gas pass through the reactor, pollutants are transferred from the gaseous phase to the liquid or the solid phase on to the media where biodegradation of pollutants is carried out by microorganisms (Shareefdeen et al. 2011). The various steps involved in biofiltration process (Soccol et al. 2003, Sakunthala et al. 2013) are:

- Diffusion from bulk waste gas to media and then within the media particles.
- Solubilization of odorous compounds in water within media.
- Adsorption to organic and inorganic fraction of media.
- Biodegradation (bio-oxidation) by microbes in media.



(Source: Envirogen technologies)

Fig. 1: A typical biofilter.

The key aspect in the biofiltration is providing an organic media that can sustain the specific microorganisms that can biologically oxidize the pollutants. Once absorbed in the biofilm layer or dissolved in the water layer around the biofilm, the contaminants, usually an organic molecule, is available as food serving as carbon and energy source for the growth and metabolic activities of microorganism. Often the start of biodegradation process by these microbes, the end products particularly carbon dioxide, water and treated air are exhausted from the biofilter (Adler 2001, Mudliar et al. 2010). The actual biochemical reactions involved are very complex. Several different types of microorganisms cooperate in a network of co-metabolic levels wherein at each stage a specific compound may be broken down into less complex compounds. A number of extensive reviews and studies regarding the development and technical aspects of biofiltration have already been published (Swanson & Loehr 1997, McNevin & Barford 2000). Additionally, much effort has been put into developing models to predict biofilter performance under various conditions (Shareefdeen & Shaikh 1997, Jorio et al. 2003, Iranpour et al. 2005).

Types of biofilters: Biofilters can be classified into several types depending on the layout (Mudliar et al. 2010, Janni et al. 2011). Biofilters can be open or closed type. In open-bed biofilters the media used is uncovered and exposed to weather conditions, including rain, snow, and temperature extremes (Nanda et al. 2012). Open-bed biofilters are the most common type biofilters used to treat air from animal facilities. Some open-bed biofilters can have roofs over the biofilter to provide some weather protection. Closed-bed biofilters on the other hand are enclosed with a small exhaust port for venting of the cleaned air. Nicolai & Lefers (2006) pointed out that closed biofilters are more expensive than open biofilters which are more commonly used for animal agriculture.

Biofilters can also be classified as horizontal or vertical type biofilters. Vertical gas flow biofilters offer an option if enough surface area and space are not available. These biofilters are relatively inexpensive to build and easy to maintain (Janni et al. 2011). However horizontal biofilters have larger footprints than vertical biofilters. They require lot of space and also in horizontal biofilters the media tends to settle over time (Nicolai et al. 2005, Janni et al. 2011). Media settling causes reduced air flow through the bottom portion of the filter and increasing air flow through the top portion of the filter, resulting in gas channelling due to compaction at the base of the filter. One potential option to reduce compaction is a two stage biofilter design (Chen et al. 2008b).

Vertical biofilters are being developed to reduce the footprints found in horizontal biofilters. Vertical biofilters use less surface area than a horizontal biofilter for treating the same airflow. The media in a vertical biofilter is placed between two vertical support structures and across the top. The air passes either horizontally through the vertical supports or through the top. The vertical gas flow biofilter can be further divided into up flow or down flow. Comparing the down flow and up flow biofilters, the up flow type is generally cheaper than down flow in terms of construction costs (Nicolai & Lefers 2006). Therefore, up flow open bed biofilters are preferred for agricultural use (Janni et al. 2011). However, from the water supply and water distribution concerns, the down flow design is preferred. An overhead sprinkling system directly supplies water to the quick drying top media to prevent the formation of a dried media layer that often forms at the bottom of an up flow biofilter.

Biofilter media: Biofiltration process largely depends on the medium that should provide all the necessary environmental conditions for the resident microbial population to achieve and maintain high biodegradation rates. A good biofilter packing material should have a large surface area, high water retention capacity, low bulk density, high porosity, structural integrity, and a buffer capacity towards acidification and to maintain high contaminant loads (Nicolai & Schmidt 2005, Morgan-Sagastume & Noyola 2006, Menikpura et al. 2007, Mudliar et al. 2010, Abdehagh et al. 2011, Chan & Hoff 2011). In order to homogenize the gas flow, reduce compaction and pressure drop, improve porosity, prevent cracking and channelling and augment the adsorptive capacity of the packing material, such as compost, peat, and wood chips, some bulking agents can be added (Morgenroth et al. 1996, Webster et al. 1996). Table 3 shows various types of natural media used in a biofilter along with their physico-chemical characteristics.

Synthetic media that can be used in a biofilm are ceramics (Govind & Bishop 1995), lava rock (Chitwood & Devinny 2001) and a number of fiber based materials (Kim et al. 1998). A few experiences of using rockwool can be found in biotrickling filters (Ostlie-Dunn et al. 1998). Rockwool material is structurally stable, chemically and mechanically resistant and provides good support material for microorganisms (Ostlie-Dunn et al. 1998). Fiber mats with low compre-ssibility and high void fraction develops the lowest pressure drops. Various synthetic media that can be used in a biofilter are biofiber fill, net like plastic fill, plastic balls, coral sands, porcelain rings (Nanda et al. 2012) etc. New porous materials such as zeolites and metal oxides are proposed to be used as adsorbents for VOCs removal (Zhang et al. 2012).

Microorganisms: Microorganisms are the agents that carry out the biodegradation of VOC's and odours. The choice of a proper colony of microorganism is fundamental for successful biofilter operation. Selection of the microbial culture for biofiltration is usually done as per the composition of the waste air and the ability of the microorganism to degrade the pollutant present in it (Nanda et al. 2012). For the degradation of VOCs, usually mixed populations of bacteria or fungi have been extensively used (Cox & Deshusses 1999). Mixed cultures often originating from wastewater treatment plants or of similar origin have been used as inoculums (Morgenroth et al. 1996). This type of general inoculums has the advantage of containing a vast variety of rugged organisms with a wide degradative ranges and the ability to work in a fluctuating environment. However, acclimation times for some microbes may be long and the degradation of some compounds may be therefore, difficult to accomplish. Inoculation using specific microbial species has been shown to reduce the acclimation period and enhance removal efficiency. After an acclimatization period, the most resistant population to the toxic VOC is naturally selected and a microbial hierarchy is established in the bed. *Bacillus* has been found effective in degrading oxidation products from frying activities, as many bacilli produce extracellular hydrolytic enzymes that breakdown lipids, permitting the organisms to use these products as carbon sources and electron donors (Becker et al. 1999). Methylotrophic microbes of *Hyphomicrobium* genus (Pol et al. 1994, Smet et al. 1996b) and autotrophic microbes of *Thiobacillus* genus has been found efficient in degrading

Table 3: Characteristics of various filter media.

Material	Porosity	Moisture capacity	Nutrient capacity	Useful life	Cost
Peat	Average	Good	Good	Good	Medium
Soil (heavy loam)	Poor	Good	Good	Good	Very Low
Compost (yardwaste)	Average	Good	Good	Good	Low
Wood chips	Good	Average	Average	Average	Low
Straw	Good	Average	Poor	Poor	Low

(Source: Janni et al. 2011)

Table 4: Various types of microorganisms used in a biofilter.

Compound	Microorganism
Methanol	*Pseudomonas* spp., *Hyphomicrobium* spp., *Thiobacillus* spp.
Hydrogen sulphide	*Pseudomonas* spp. *Bacillus cereus, Streptomyces* spp.
Dimethyl amines	*Pseudomonas aminovorans, Arthrobacter* sp., *Bacillus* sp.
Trimethyl amines	*Pseudomonas aminovorans, Hyphomicrobium* spp.
Acetic acid	*Acetobacter ascendens*
Aniline	*Nocardia spp. and Pseudomonas* spp.
Carbon disulphide	*Thiobacillus* spp.
Phenol	*Pseudomonas putida*

(Source: Rappert & Muller 2005)

dimethyl sulphide (DMS) and dimethyl disulphide (DMDS) compounds (Chung et al. 1998). These organisms utilize methyl sulphides as an energy source, a carbon source, or both, thereby degrading these compounds. However, it is difficult to draw a boundary between different physiological types of bacteria in the context of their taxonomic position and one should expect nature to have a complete spectrum of bacteria with combinations of methylotrophic and autotrophic capabilities (Suylen & Kuenen 1986). In a biofilter, the degrading species represents between 1 and 15% of the total population (Delhomenie et al. 2001a). Table 4 shows various types of microorganisms used in biofiltration process.

Parameters affecting biofiltration: A number of parameters need to be addressed for successful working of a biofilter.

***Moisture*:** Moisture is an important parameter for the growth and survival of the resident microorganisms (Van Lith et al. 1997). Inadequate moisture content can lead to compaction of the media, incomplete degradation of raw gas and the establishment of anaerobic zones that may release odorous compounds (Mudliar et al. 2010, Janni et al. 2011). The ideal water content varies with different filter media, depending on, for example, media surface area and porosity. For an organic filter media, a moisture content of 40-60% (by weight) has been recommended (Van Lith et al. 1997); however no evidence exists on the optimum moisture content for synthetic media. Pre-humidification of the inlet gas stream sustains moisture levels in a biofilter (Mudliar et al. 2010). Also, it is often essential to provide direct application of water to the bed through a sprinkler system at the top of the bed (Mudliar et al. 2010). The impact of moisture on the microbial activity has been studied by several authors. As per the study carried out by Menikpura et al. (2007), activity of microbes has been found to get decreased under dry conditions compared to activity of microbes under wet conditions. Besides, formation of dry spots can result due to drying of the packing material that can cause non-uniform gas distribution and thereby decreasing the activity of microorganisms (Shareefdeen & Singh 2005). Also, drying at the air inlet port in a biofilter can lead to decreased pollutant removal rate over time (Sakuma et al. 2009), hence pre-humidification of the inlet gas stream is very obligatory.

***pH*:** Most microorganisms require a specific pH range, hence, a variation in pH could powerfully affect their activity and hence corresponding biofilter performance (Wu et al. 2006). The two important processes occurring in a biofiltration process viz., absorption of waste gases and microbial activity occurring in a biofilter are strictly related to pH. Optimal pH for biofilter operation is in the 7 to 8 range to inspire and quicken the absorption process and maximizes the microbial action and hence maximizes odour removal efficiency (Swanson & Loehr 1997). Degradation of VOC's containing hetero-atoms (S,O and N) can result in acidic conditions in the biofilter due to formation of acidic products which tend to reduce the activity of microbes (Christen et al. 2002), and also cause corrosion problems in downstream conduits (Webster & Devinny 1998). Similar observations during VOC degradation due to formation of acidic intermediates have been reported by several authors (Shareefdeen & Singh 2005, Maestre et al. 2007).

Soil exhibits the best intrinsic pH buffering capacity followed by compost and wood chips, among the various other organic packing materials used in biofilters (Kennes & Thalasso 1998, Mudliar et al. 2010). Peats are naturally acidic (pH 3.0-4.0) and have little buffering capacity. Buffering capacity must be satisfactory to prevent acid accumulation in biofilters, when used to treat high concentration of odorants. The addition of limestone or other water insoluble alkalis to the filter packing has proven to be a feasible remedy against pH drop (Ottengraf & VanDenOever 1983).

***Nutrients*:** In laboratory studies, along with water supply, nutrients needs to be provided (Cloirec et al. 2001, Chung et al. 2007), as long-term utilization of nutrients in the beds lead to progressive exhaustion of the intrinsic nutritive resources (Mudliar et al. 2010). This progressive nutrient shortage then becomes a limiting factor for the long-term biofiltration performance (Delhomenie et al. 2001a). Organic media, such as compost, usually supply abundant quantities of nutrients in the available form (Leson & Winer 1991, Sun et al. 2000). Studies have confirmed that irrespective of the filtering material employed, the steady addition of nutrients is necessary to withstand a suitable microbial degradation activity. Therefore, it is necessary to provide nutrients for biofilters packed with inert media. Common forms, which can be provided in solution, are ammonium nitrate (NH_4NO_3), ammonium chloride (NH_4Cl), magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), and dipotassium hydrogen phosphate (K_2HPO_4) (Clark et al. 2004, Mudliar et al. 2010).

***Temperature*:** Microorganisms tolerate a wide range of temperatures. The optimal temperature for various species ranges widely, but most biofiltration processes have been achieved at temperatures in the mesophilic range of 20-45°C and 35-37°C, often noted as the optimum temperature (Swanson & Loehr 1997). Lower temperatures especially during winter months have been found reducing the activity of microbial degradation, since lower temperatures may freeze the filter media thereby restricting the flow of waste air through the filter media (Janni et al. 2011). The optimum temperature range for hydrogen sulphide (H_2S) removal is 35 to 50°C. Very often, there is a gradual increase in temperature due to microbial respiration and exothermic reactions in the filter (Nanda et al. 2012).

***Oxygen levels*:** There must be an appropriate oxygen level for the effective working of a biofilter, since inadequate levels of oxygen affect the performance of biofilters. Generally in most applications, biofilter operations pursue to avoid anaerobic conditions. This is because, presence of even micro-anaerobic conditions can lead to the formation of compounds which themselves are odorous and this affects the overall goal of removing odorants and VOC's (Mudliar et al. 2010). However, the necessity of the oxygen level is very case specific since different microorganisms have different requirements as can be seen from various studies, conducted by separate authors. Some studies have found that there was no substantial improvement when oxygen level was amplified in the simultaneous removal of a mixture of methyl ethyl ketone (MEK) and methyl isobutyl ketone (MIBK) (Deshusses et al. 1996).

***Biofilter media depth*:** The biofilter media constitute the main part of a biofilter because it provides the support for microbial growth. A biofilter bed should have some important characteristics as recognized by Bohn (1992), such as; (a) high specific surface area for growth of a microbial biofilm and gas-biofilm mass transfer, (b) high porosity to enable homogeneous distribution of gases, (c) a decent water retention capacity to avoid bed drying, (d) existence and availability of indigenous nutrients, and (e) presence of a compact and diverse indigenous microflora. For onsite biofiltration media depths should be ranging from 0.3 to 1 m. The biofilter media depth, along with air flow rate, is a key factor to affect pressure drop and removal efficiency. Nicolai & Janni (1999) suggested that compost/wood chip based media should have a minimum depth between 0.15 and 0.3m, with an ideal minimum depth of 0.25m. Khammar et al. (2005) evaluated in an experiment that peat media indicated 75% and 55% of removal efficiency for aromatic compounds at a media depth between 0.3 and 1 m for two pilot scale bio-filters, respectively. Higher media depth has higher potential of removal efficiency. Though, higher media depth results in higher pressure drop which is linearly related to media depth at a constant air flow rate. The media depth of 0.25 to 0.50 m has been recommended as prime for agricultural biofilters.

***Pressure drop*:** Pressure drop is one of the prime considerations for effective operation of full scale biofilters. The pressure drop is closely linked to media type, media depth, and air flow rate through the media. Agricultural ventilation fans should be run at a pressure drop less than 62 Pascal's (0.25 in water) for better removal efficiency (Nicolai & Janni 1998b). Wood chip media appeared to be the most promising biofilter media since they had a low pressure drop of around 45 Pascal's/meter (pa/m) at a superficial air velocity of 0.13 m/s (Phillips et al. 1995). Nicolai & Janni (2001a) demonstrated that the pressure drop was found to be related to percent void space in the biofilter media and there was a direct relationship between media unit pressure drop and unit airflow rate for a mixture of compost and wood chips.

Likewise, a wood chip alone biofilter showed a linear relationship between the media unit pressure drop and unit airflow rate (Chen et al. 2008b).

***Biofilter costs*:** Biofiltration technology has been proven to be the most cost effective method for treating ventilation exhaust air as compared to conventional physical and chemical methods (Sakunthala et al. 2013). Different types of biofilters vary in their construction and operation costs which may be further abridged by introducing new strategies such as partial biofiltration. However it has been found by many authors that biofilter offer a best odour treatment technology, having reasonable capital and operating costs (Mudliar et al. 2010, Sakunthala et al. 2013).

***Removal efficiency*:** Most odour and gas emissions from various sources are byproducts of anaerobic decomposition and transformation of organic matter by microorganisms (Nicolai et al. 2006). Biofilters have the capability to treat a broad spectrum of gaseous compounds (Janni et al. 2001). Wood chip based biofilters have shown removal efficiency of 76%-93% in a research conducted by Chen et al. (2008a) from a deep pit swine facility, for 16 different odorous compounds identified in the exhaust air. Lot of research has been conducted on the removal efficiency of NH_3 and H_2S both in laboratories and onsite. About 95 percent of hydrogen sulfide (H_2S) and 80 percent of ammonia (NH_3) can be reduced by a well designed and managed biofilter (Premkumar et al. 2013). A high removal efficiency with a value up to 100% was reported for both NH_3 and H_2S in laboratory studies (Kim et al. 2002, Choi et al. 2003, Kastner et al. 2004, Morgan-Sagastume & Noyola 2006, Chung et al. 2007) where optimum conditions were well controlled. Maintaining appropriate conditions, especially a proper range of media moisture content, is critical for a fruitful biofilter operation. A wet scrubber coupled with a biofilter may benefit overall system performance, especially for removing NH_3.

ADVANTAGES AND DISADVANTAGES

Advantages

1. In comparison to other methods such as thermal processes that produce different types of oxides, biofiltration produces simpler by-products such as waste biomass that can be easily disposed off. Also chemical oxidation processes produce chlorine and chlorinated products which have high negative impacts (Govind & Bishop 1998)
2. The investment and operating costs of biofiltration are less as compared to other physical and chemical odour treatment methods. There is no chemical handling in biofiltration, whereas in chemical oxidation, chemicals such as hypochlorite, hydrogen peroxide, chlorine dioxide, etc. have to be stored and handled carefully.
3. Biofilters usually treat large volumes of low concentration VOCs and other odorants (Mudliar et al. 2010).

Disadvantages

1. One disadvantage is that systems may require a period of gas conditioning and that the bacteria in the microbiological media can be sensitive to changes in inlet conditions (Duffee et al. 1991). Also feed gas must not be lethal to microorganisms.
2. Although biofilters are capable of versatility, some applications have shown that mercaptan and organic sulfide removal efficiencies decrease over time to unacceptable levels due to pH changes in the media (Greer et al. 2000).
3. Proper temperature and humidity control is necessary in biofilters. Also the efficiency of biofilters decreases for air streams with large concentrations of VOC's.

CONCLUSION

This review gives an idea about the role of biofiltration techniques that can be employed effectively to treat biodegradable pollutants such as volatile organic and inorganic compounds. Many studies have been conducted using biofiltration techniques with overall appreciable results. The evaluation of the biofilter system indicates that it is a feasible air pollution control system for controlling odorous emissions and is a cost effective alternative method to more traditional treatment methods.

REFERENCES

Abdehagh, N., Taghinejad Namini, M., Heydarian, S.M., Bonakdarpour, B. and Zare, D. 2011. Performance of a biotrickling filter employing *Thiobacillus thioparus* immobilized on polyurethane foam for hydrogen sulfide removal. Iran Journal of Environment Health Science and Engineering, 8(3).

Adler, S.F. 2001: Biofiltration-a primer. Chemical Engineering Progress, 97(4): 33-41.

Becker, P., Koster, D., Popov, M.N., Markossian, S., Antrankian, G. and Markl, H. 1999. The biodegradation of olive oil and the treatment of lipid-rich wool scouring wastewater under aerobic thermophilic conditions. Water Research, 33(3): 653-660.

Bellis, M. 2007. History of biofilters and biofiltration treatment. Retrieved from http://inventors.about.com/od/bstartinventions/a/biofiltration.htm

Bohn, H. 1992. Considering biofiltration for decontaminating gases. Chemical Engineering Progress, 88: 34-40.

Chen, L., Hoff, S.J., Koziel, J.A., Cai, L., Zelle, B. and Sun, G. 2008a. Performance evaluation of a wood chip-based biofilter using solid-phase microextraction and gas chromatography-mass spectrometry-olfactometry. Bioresource Technology, 99(16): 7767-7780.

Chen, L., Hoff, S.J., Cai, L. and Koziel, J.A. 2008b. Odor reduction during biofiltration as affected by air flow rate and media moisture content. ASABE, No. 083859.

Chen, L. and Hoff, S.J. 2011. Mitigating odors from agricultural facilities: A review of literature concerning biofilters. Advances in Chemical Engineering and Science, 1: 72-76.

Chen, L. and Hoff, S.J. 2012. A two-stage wood chip-based biofilter system to mitigate odors from a deep-pit swine building. Digital repository @ Iowa State University. Agricultural and Biosystems Engineering (ASBE), No. 9631.

Chitwood, D.E. and Devinny, J.S. 2001. Treatment of mixed hydrogen sulfide and organic vapors in a rock medium biofilter. Water Environment Research, 73(4): 426-435.

Choi, J.H., Kim, Y.H., Joo, D.J., Choi, S.J., Ha, T.W., Lee, D.H., Park, I.H. and Jeong, Y.S. 2003. Removal of ammonia by biofilters: A study with flow-modified system and kinetics. Journal of the Air & Waste Management Association, 53(1): 92-101.

Christen, P., Domenech, F., Michelena, G., Auria, R. and Revah, S. 2002. Biofiltration of volatile ethanol using sugar cane bagasse inoculated with Candida utilis. Journal of Hazardous Material, 89: 253-265.

Chung, Y.C., Huang, C.P., Pan, J.R. and Tseng, C.P. 1998. Comparison of autotrophic and mixotrophic biofilters for H_2S removal. Journal of Environmental Engineering, 124(4): 362-367.

Chung, Y.C., Ho, K.L. and Tseng, C.P. 2007. Two-stage biofilter for effective NH_3 removal from waste gases containing high concentrations of H_2S. Journal of the Air & Waste Management Association, 57(3): 337-347.

Clark, O. G., Edeogu, I., Feddes, J., Coleman, R.N. and Abolghasemi, A. 2004. Effects of operating temperature and supplemental nutrients in a pilot-scale agricultural biofilter. Canadian Biosystems Engineering, 46: 6.7-6.16.

Cloirec, P.L., Humeau, P. and Ramirez-Lopez, E.M. 2001. Biotreatments of odours and performances of a biofilter and a bioscrubber. Water Science and Technology, 44(9): 219-226.

Cox, H.J. and Deshusses, M.A. 1999. Chemical removal of biomass from waste air biotrickling filters: Screening of chemicals of potential interest. Water Research, 33: 2383-2392.

CPCB 2008. Guidelines on odour pollution & its control: A report. CPCB, Ministry of Environment & Forests, Govt. of India.

Delhomenie, M.C., Bibeau, L., Gendron, J., Brzezinski, R. and Heitz, M. 2001a. Air treatment by biofiltration: Influence of nitrogen concentration on operational parameters. Industrial Engineering Chemistry Research, 40: 5405-5414.

Deshusses, M.A., Hamer, G. and Dunn, U. 1996. Transient state behaviour of a biofilter removing mixtures of vapours of MEK and MIBK from air. Biotechnology and Bioengineering, 49: 587-598.

Duffee, Richard A., Martha A. O'Brien, and Ned Ostojic 1991. Use of biofiltration for odor control. Recent developments and current practices in odor regulations, controls and technology. Pittsburgh, PA. Air and Waste Management Association, 92-103.

Envirogen Technologies. A lifecycle performance company. www.envirogen.com

Govind, R. and Bishop, D.F. 1995. Effect of support media in biofiltration. In: Proceedings of the IGT 8th International Gas, Oil, and Environmental Biotechnology Symposium, Colorado Springs.

Govind, R. and Bishop, D.F. 1998. Biofiltration for treatment of volatile organic compounds (VOC's) in air. In: Biodegradation Technology Developments, Volume II, Eds. Subhas K. Sikdar and Robert L. Irvine, Technolmic Publishing Company, Lancaster, PA.

Greer, Glenn, Elizabeth Wong and Sergio Ivan Velez 2000. Sweet smell of success: Florida's scentsible solutions to sulfide odour control. Water Environment and Technology.

Iranpour, R., Cox, H.H.J., Deshusses, M.A. and Schroeder, E.D. 2005. Literature review of air pollution control biofilters and biotrickling filters for odor and volatile organic compound removal. Environmental Progress, 24(3): 254-267.

Iwasaki, Y. 2004. Olfactory measurement of odor (New Version). Japan Association on Odor Environment, 145-152.

Janni, K.A., Maier, W.J., Kuehn, T.H., Yang, C.H., Bridges, B.B. and Vesley. D. 2001. Evaluation of biofiltration of air, an innovation air pollution control technology. ASHRAE Trans., 107(1): 198-214.

Janni, K.A., Nicolai, R.K., Hoff, S. and Stenglein, R.M. 2011. Biofilters for odor and air pollution mitigation in animal agriculture. Air Quality in Animal Agriculture, No. 15538.

Jorio, H., Bibeau, L., Viel, G. and Heitz, M. 2000. Effects of gas flow rate and inlet concentration on xylene vapors biofiltration performance. Chemical Engineering Journal, 76: 209-221.

Jorio, H., Payre, G. and Heitz, M. 2003. Mathematical modeling of gas-phase biofilter performance. Journal of Chemical Technology and Biotechnology, 78: 834-846.

Kastner, J.R., Das, K.C. and Crompton, B. 2004. Kinetics of ammonia removal in a pilot scale biofilter. Trans. ASAE, 47(5): 1867-1878.

Kennes, C. and Thalasso, F. 1998. Waste gas biotreatments technology. Journal of Chemical Technology and Biotechnology, 72: 303-319.

Khammar, N., Malhautier, L., Degrange, V., Lensi, R., Godon, J. J. and Fanlo, J.L. 2005. Link between spatial structure of microbial communities and degradation of a complex mixture of volatile organic compounds in peat biofilters. Journal of Applied Microbiology, 98(2): 476-490.

Kim, N. J., Hirai, M. and Shoda, M. 1998. Comparison of organic and inorganic carriers in removal of hydrogen sulfide in biofilters. Environmental Technology, 19: 1233-1241.

Kim, H., Kim, Y.J. and Chung, J.S. 2002. Long-term operation of a biofilter for simultaneous removal of H_2S and NH_3. Journal of the Air & Waste Management Association, 52: 1389-1398.

Leson, G. and Winer, A.M. 1991. Biofiltration: An innovative air pollution control technology for VOC emissions. Journal of Air & Waste Management Association, 41(8): 1045-1054.

Maestre, J.P., Gamisans, X., Gabriel, D. and Lafuente, J. 2007. Fungal biofilters for toluene biofiltration: Evaluation of the performance with four packing materials under different operating conditions. Chemosphere, 67: 684-692.

McNevin, D. and Barford, J. 2000. Biofiltration as an odour abatement strategy. Biochemical Engineering Journal, 5: 231-242.

Menikpura, S.N.M., Ariyawansha, S.W.G.R.T.K., Basnayake, B.F.A. and Tharinda, Y.G.W.G.M.C. 2007. Design and development of biofilters for controlling odor emissions from composting of municipal solid waste. In: Proceedings of the International Conference on Sustainable Solid Waste Management, Chennai, India, pp. 250-257.

Metcalf and Eddy. 2003. Wastewater Engineering, Treatment and Reuse. McGraw-Hill, New York.

Morgenroth, E., Schroeder, E.D., Chang, D.P.Y. and Scow, K.M. 1996. Nutrient limitation in a compost biofilter degrading hexane. Journal of the Air & Waste Management Association, 46(4): 300-308.

Morgan-Sagastume, J.M. and Noyola, A. 2006. Hydrogen sulfide removal by compost biofiltration: Effect of mixing the filter media on operational factors. Bioresource Technology, 97(13): 1546-1553.

Mudliar, S., Giri, B., Padoley, K., Satpute, D., Dixit, R., Bhatt, P., Pandey, R., Juwarkar, A. and Vaidya, A. 2010. Bioreactors for treatment of VOCs and odours-A review. Journal of Environmental Management, 91: 1039-1054.

Nanda, S., Sarangi, P.K. and Abraham, J. 2012. Microbial biofiltration technology for odour abatement: An introductory review. Journal of

Soil Science and Environmental Management, 3(2): 28-35.
Nicolai, R.E. and Janni, K.A. 1998b. Biofiltration-adaptation to livestock facilities. In: Proceedings of USC-TRG Conference on Biofiltration, Los Angeles, California, pp. 99-106.
Nicolai, R.E. and Janni, K.A. 1999. Effects of biofilter retention time on emissions from dairy, swine, and poultry buildings. ASAE, No. 994149, St. Joseph, Michgan.
Nicolai, R.E. and Janni, K.A. 2001a. Biofilter media mixture ratio of wood chips and compost treating swine odors. Water Science and Technology, 44(9): 261-267.
Nicolai, R.E., Lefers, R.S. and Pohl, S.H. 2005. Configuration of a vertical biofilter. In: Livestock Environment VII: Proceedings of 7th International Symposium, Tami Brown-Brandl and Ronaldo Maghirang, eds., pp. 358-364.
Nicolai, R. and Schmidt, D. 2005. Biofilters, livestock development in South Dakota; environmental and health. South Dakota State University, College of Agriculture & Biological Sciences, Cooperative Extension Service/USDA Cooperating, pp. 2-8.
Nicolai, R.E., Clanton, C.J., Janni, K.A. and Malzer, G.L. 2006. Ammonia removal during biofiltration as affected by inlet air temperature and media moisture content. Trans. ASABE, 49(4): 1125-1138.
Nicolai, R.E. and Lefers, R.M. 2006. Biofilters used to reduce emissions from livestock housing: A literature review. In: Workshop on Agricultural Air Quality, Washington, D.C.: Dept of Communication Services, North Carolina State University, Raleigh, NC., pp. 952-960.
Ostlie-Dunn, T.L., Domack, R., Newell, J.A., Scott, A.M. and Kozliak, E.I. 1998. Fibre-based trickle bed bioreactors for air purification. In: Proceedings of the USC-TRG Conference on Biofiltration, Los Angeles, pp. 203-210.
Ottengraf, S.P.P. and Van den Oever, A.H.C. 1983. Kinetics of organic compound removal from waste gases with a biological filter. Biotechnology Bioengineering, 25: 3089-3102.
Phillips, V.R., Scotford, I.M., White, P.R. and Hartshorn, R.L. 1995. Minimum-cost biofilters for reducing odours and other aerial emissions from livestock buildings: Part 1. Basic airflow aspects. J. Agricultural Engineering Research, 62(3): 203-214.
Pol, A., Op den Camp, H.J.M., Mees, S.G.M., Kersten, M.A.S.H. and Van der Drift, C. 1994. Isolation of a dimethylsulfide-utilizing Hyphomicrobium species and its application in biofiltration of polluted air. Biodegradation, 5: 105-112.
Premkumar, R., Devi, S., Krishnamohan, N. and Balaji, A. 2013. Wood chip based filter media for removal of pollutants from waste air: review. International Journal of ChemTech Research, 5(6): 2830-2836.
Rappert, S. and Muller, R. 2005. Microbial degradation of selected odorous substances. Waste Management, 25: 940-954.
Sakuma, T., Hattori, T. and Deshusses, M.A. 2009. The effects of a lower irrigation system on pollutant removal and on the microflora of a biofilter. Environmental Technology, 30: 621–627.
Sakunthala, M., Sridevi, V., Chandana lakshmi, M.V.V. and Vijay kumar, K. 2013. A Review: The description of three different biological filtration processes and economic evaluation. Journal of Environmental Science, Computer Science and Engineering & Technology, 2(1): 91-99.
Shareefdeen, Z.M. and Shaikh, A.A. 1997. Analysis and comparison of biofilter models. Chemical Engineering Journal, 65: 55-61.
Shareefdeen, Z.M. and Singh, A. 2005. Biotechnology for Odor and Air Pollution Control. Springer, Berlin, Heidelberg, New York.
Shareefdeen, Z.M., Ahmed, W. and Aidan, A. 2011. Kinetics and modeling of H_2S removal in a novel biofilter. Advances in Chemical Engineering and Science, 1: 72-76.
Soccol, R.C., Woiciechowski, A.L., Vandenberghe, L.P.S., Soares, M., Neto, G.K. and Soccol, V.T. 2003. Biofiltration: An emerging technology. Indian Journal of Biotechnology, 2: 395-410.
Smet, E., Van Langenhove, H. and Verstraete, W. 1996b. Long-term stability of a biofilter treating dimethyl sulphide. Applied Microbiological Biotechnology, 46: 191-196.
Sun, Y., Clanton, C.J., Janni, K.A. and Malzer, G.L. 2000. Sulfur and nitrogen balances in biofilters for odorous gas emission control. Trans. ASAE, 43(6): 1861-1875.
Suylen, G.M.H. and Kuenen, J.G. 1986. Chemostat enrichment and isolation of Hyphomicrobium EG. Antonie van Leeuwenhoek, 52: 281-293.
Swanson, W.J. and Loehr, R.C. 1997. Biofiltration: Fundamentals, design and operations principles, and applications. Journal of Environmental Engineering, 123: 538-546.
Van Lith, C., Leson, G. and Michelsen, R. 1997. Evaluating design options for biofilters. Journal of the Air and Waste Management Association, 47(1): 37-48.
Webster, T.S., Devinny, J.S., Torres, E.M. and Basrai, S.S. 1996. Biofiltration of odors, toxics and volatile organic compounds from publicly owned treatment works. Environmental Progress, 15(3): 141.
Webster, T.S. and Devinny, J.S. 1998. Biofiltration. In: Meyers, R.A. (Ed.), Encyclopedia of Environmental Analysis and Remediation, John Wiley & Sons, New York 653-665.
Wu, D., Quan, X., Zhang, Y. and Zhao, Y. 2006. Long-term operation of a compost-based biofilter for biological removal of n-butyl acetate, p-xylene and ammonia gas from an air stream. Biochemical Engineering Journal, 32(2): 84-92.
Zhang, W., Qu, Z., Li, X., Wang, Y., Ma, D. and Wu, J. 2012. Comparison of dynamic adsorption/desorption characteristics of toluene on different porous materials. Journal of Environmental Sciences, 24(3): 520-528.