

Review

Microbial biofiltration technology for odour abatement

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Odour is a serious complaint associated with waste air emissions that creates nuisance due to its malodorous behaviour. Its treatment process ranges from physical, chemical to biological means. A biological treatment system has several advantages over the physical and chemical technologies in being: ecofriendly, more efficient with low operational cost and characterized by high flow rates of waste gas with low concentration of contaminants. Application of microorganisms in waste treatment has long been realized, especially in degrading various compounds in the waste gas that cause odour. However, understanding the type of microorganism and its metabolism for the particular odorant is very crucial in designing a biological treatment system. Biofilters are well-known biological filtration systems that employ microorganisms for treating odours from waste gases. This report describes the generation of odorants from different sources and their possible degradation by suitable microbial cultures. In addition, comparisons among physiochemical and biological methods for odour abatement have been discussed. Nevertheless, the type of biofilter, its packing material and other reaction conditions for an effective biofiltration have also been considered.

Keywords: Air pollution; biofiltration; open-type biofilters; closed-type biofilters; microbial biodegradation.

INTRODUCTION

Pollution is one of the serious issues the world is facing today. Since industrial revolution, there have been major progressions in agriculture, manufacture, transport and most importantly global industrialization. In the last few decades, the onset of this rapid urbanization has led to an increase in the rate of pollution, particularly air pollution. Air pollution is the introduction of contaminants in form of chemicals, particulate matter or biological materials that cause discomfort and are hazardous to living beings. With respect to air pollution, odour is a major concern in the present day because of its malodorous property and is considered a nuisance to the general public.

Odour is often a complaint in urban areas which is associated with the waste gas emissions. Odour emissions are important sources of air pollution from industries, livestock production houses, composting plants, food processing industries, dairy industries,

wastewater treatment facilities, pharmaceutical industries, rubber processing plants, pulp and paper industries, textile industries, petroleum refineries, paint finishing plants, chemical industries etc. (Rappert and Muller, 2005). 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 and Muller, 2005). It is estimated that only 10^8 to 10^9 molecules of odorant vapour in the human nose is enough to trigger detection. More than 100 kinds of odorous gases are emitted from composting processes, of which the nitrogen-containing compounds, sulphur-containing compounds and short-chain fatty acids have gained much attention due to their low threshold limits (Chung, 2007).

Odour - generation and composition

Generation of odour varies as per the operation and industry. In a biological-mechanical treatment process for

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municipal solid waste, odours are caused due to organic matters decomposition and anaerobic fermentation (Lui et al., 2009). In paper industries, odours are produced due to the treatment of wood and straw with sodium hydroxide (Bajpai et al., 1999). Irrespective of the treatment and condition of processing, odour generation depends on the composition of the raw material. In a piggery facility, odours result from anaerobic decomposition of animal manure to unstable intermediate byproducts resulting in a complex mixture of over 168 volatile compounds of which 30 are odorous (O'Neill and Phillips, 1992).

Odour includes some volatile inorganic compounds (VIC) such as dimethyl trisulphide (DMTS); volatile organic compounds (VOC) such as dimethyl sulfoxide (DMSO), dimethyl disulphide (DMDS), limonene, α -pinene, ethylbenzene, benzene, styrene and toluene; amines such as dimethylamine (DMA), trimethylamine (TMA), diethylamine (DEA) and triethylamine (TEA); pyrazine compounds, especially alkylpyrazines such as 2,3-diethyl-5-methylpyrazine (DM) and 2,5-dimethylpyrazine (DP) (Muller and Rappert, 2010; Rappert and Muller, 2005; Van Derme et al., 1992).

Some principal volatile organic compounds (VOCs) from municipal solid waste composting facilities include aromatic hydrocarbons, D-limonene, chlorinated compounds and ketones (Eitzer, 1995). During the aerobic composting of municipal solid waste, alcohols, carbonyl compounds, terpenes, esters, ethers and sulphur compounds are produced in the waste gases (Smet et al., 1999). However, Pierucci et al. (2005) recognized the most important compounds in the effluent gases from biological treatment of municipal solid waste as terpenes, monocyclic arenes (C₂, C₃ and C₄ benzenes), alkanes, halogenated compounds and esters. In case of paper industries, the cause of odour is residual sulphur-containing protoplasm of plant biomass which reacts with alkali (sodium hydroxide) to give mercaptans and organic sulphides during digestion (Bajpai et al., 1999). Natural biological reactions in pig production houses result in organic acids, aldehydes, alcohols, carbonyls, esters, amines, sulphides, mercaptans, nitrogen heterocycles, aromatics and other fixed gases that contribute to the characteristic odour of the facilities (Sheridan et al., 2002). Ammonia (NH₃) is of special interest in such areas which leads to odour, environmental acidification and pollution of ground and surface water because of its high deposition velocity (van der Eerden et al., 1998). It is a byproduct of aerobic composting of low C/N material (Hong and Park, 2005) and contributes to 50% of odours from the pig housing and manure storage (van der Peet-Schwering et al., 1999). Since, NH₃ has a low odour threshold of 4 ppm, its presence is easily detected by human olfactory (Ranau et al., 2005; Mackie et al., 1998). Hydrogen sulphide (H₂S) is of similar concern as NH₃ in pig

production houses which also originates from swine manure (Moreno et al., 2010). It has a low odour threshold of 1.1 ppb (Chung et al., 2001). Unlike NH₃ that is generated due to aerobic decomposition, H₂S is formed by anaerobic degradation of sulphur-containing organic compounds such as proteins and dissimilatory reduction of sulphate carried out by sulphate-reducing bacteria (Arogo et al., 2000).

Odour abatement

Various diminution methods are available to eliminate odorous compounds from gaseous emissions. Sufficient care must be taken to check the compatibility of the odour reduction technology with the management system and operation capabilities as a particular technology might not unify into a management scheme resulting in failure to control odours adequately (Powers, 1999). A number of physical, chemical and biological methods have been developed to abate the odours. Sometimes, a single method or a combination of two or more methods is used to treat waste gases. Unlike biological methods, physical and chemical methods have lower efficiency and higher installation and operation costs which restrict their implementation (Sheridan et al., 2002; Vaith et al., 1996). Moreover, biological processes involve equipments and set up that are simple and easy to operate.

Physiochemical methods

Commonly used physiochemical methods include gas phase, liquid phase, solid phase and combustion (Bajpai et al., 1999). Masking of odorous component is one of the gaseous phase methods in which the undesired odour is masked by a component pleasing to smell but is not eliminated which is the major drawback of the process. Oxidation of the waste gases with ozone is another gaseous phase method which removes the odour but is harmful to the bronchial tubes and is costly. In a liquid phase method, the waste gases are subjected to a liquid phase in which the pollutants are absorbed resulting in a mass transfer between gas and liquid. The method employs absorption towers and is advantageous in recovering valuable absorbed components. At times, biological methods can be coupled with liquid phase method by dispersing microorganisms in the liquid phase or immobilizing them onto a carrier material. This is because under aerobic conditions many odorous components (organic/inorganic) are oxidized by suitable microbial population into innocuous products (Rappert and Muller, 2005). In solid phase method, the waste gas is subjected to a solid phase as a result there is a mass transfer from gas to solid. The molecules of the adsorbate (waste gas) are condensed at the surface of

the absorbent material (e.g., activated carbon, alumina, silica gel and zeolites) by physical adsorption or chemisorption and are eliminated from the waste gas. Adsorption towers and pressure swing adsorption (PSA) are some technologies used in the method. PSA is a technology for separating certain gaseous components from a mixture of gases under pressure as per the components' molecular characteristics and affinity for adsorbent material. Solid phase method has an advantage of introduction of biological methods but has a limitation after saturation of the adsorbent with adsorbate which requires regeneration of the adsorbent. Combustion is another process of incinerating the organic compounds to carbon dioxide and water at high temperature. The method has restricted usage and is only used with distinctive waste gases because of poisoning of the catalyst by certain compounds.

Biological methods

Biological methods have a broad spectrum of applications. They are regarded as the most competitive systems for the deodorization of waste gases characterized by high flow rates and low concentrations of contaminants (Le Cloirec et al., 2001; Deshusses, 1997). Moreover, biological treatment is environmentally safe as it does not produce any detrimental compounds and is generally operated at natural conditions (normal atmospheric temperature and pressure) with no or gentle modifications. Nevertheless, biological filtration also known as biofiltration is regarded as the best available control technology (BACT) for treating odorous gases and a 'green technology' as it does not use any chemicals or produce any wastes that are potentially dangerous for the environment (Hort et al., 2009; Chung, 2007).

In biofiltration, organic pollutants are metabolized to carbon dioxide and water under microbial activity (Deshusses, 1997). The volatile (organic/inorganic) compounds present in the waste gases that cause odour are removed by microbial metabolism as they serve as the source of energy and/or carbon for the microorganisms (Bajpai et al., 1999). An aqueous phase (liquid medium) is required by the microorganisms for their uniform dispersion (as freely dispersed or immobilized onto carrier material) in the medium and their need for a relatively high water activity. Mass transfer of the gas into liquid is very important in the process. Oxygen is initially introduced into the liquid medium for maintaining aerobic condition for microbial metabolism and oxidation of the volatile compounds followed by the introduction of the waste gas.

Bioscrubbers, trickling filters and biofilters are the three technologies widely known as the biofiltration methods for treating waste gases. Biofilters have gained considerable

interest unlike other technologies that are more energy-intensive and less reliable due to possible washing away of active microbial inoculum from the system (Singhal et al., 1996). On the other hand, biofilters have sufficient amount of packing materials to diminish such fluctuations.

Documented to be in 1953, the conventional type biofilters were used for treating odorous sewer gases in Long Beach, California, USA (Bajpai et al., 1999). At the present day with its applications globally implemented, biofiltration is an entrenched air pollution control technology in several European countries, especially The Netherlands and Germany (Singhal et al., 1996). Nearly, 40% of animal rendering plants in New Zealand employ biofilters (Luo and van Oostrom, 1997). In USA and Canada, biofilters have already found mass recognition in many pig production houses (Moreno et al., 2010; Deutsch, 2006; Miller et al., 2004), aquaculture ponds (Rogers and Klemetson, 1985) and other similar facilities. In Asian countries like India and China, intense research on biofilters is leading to their large scale implementation (Saravanan et al., 2010; Chung, 2007; Arulneyam and Swaminathan, 2005, 2003; Chung et al., 2001).

Biofilters

Biofilters are reactors in which waste gases are allowed to pass through a porous packed bed material immobilized with suitable microbial cultures. 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 CO₂, H₂O, inorganic salts and biomass by microorganisms (Jorio et al., 2000; Deshusses, 1997). There are two types of biofilters: open system and closed system (Bajpai et al., 1999).

The open systems, often referred to as soil filters, are the conventional and the simplest forms 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 waste gas. As these systems are installed in open natural conditions they are exposed to weather fluctuations like rain, humidity, temperature etc (Bajpai et al., 1999). A few factors influencing the efficiency of biofilters are temperature, moisture content, pH, flow rate, surface loading rate, physical structure of the biofilter (Hong and Park, 2005) and microbial biomass. Modern type biofilters, referred as closed type, have the ability to regulate flow rate, pH, moisture content, pressure drop, gas conditioning, temperature, oxygen demand, removal of inhibitors (excess of NH₃ and H₂S) and enrichment of nutrients to maintain a proper microbial population for effective filtration (McNevin and Barford, 2000).

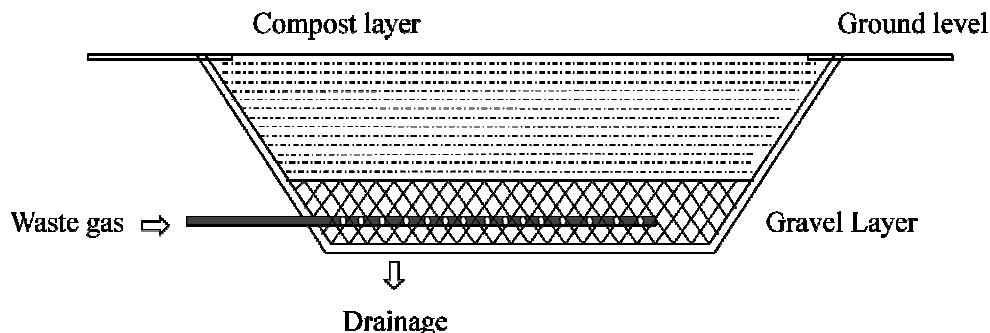


Figure 1. Cross-section of a conventional open type biofilter (Source: Bajpai et al., 1999)

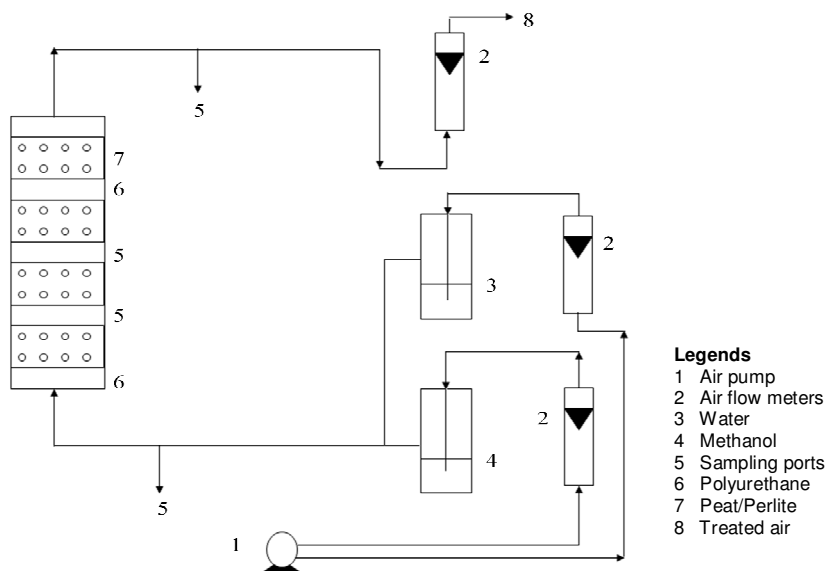


Figure 2. Schematic diagram of a closed type biofilter (Source: Bajpai et al., 1999)

Frequently, open system biofilters encounter high operating costs associated with aeration, considerable pressure drop, clogging due to biomass overgrowth and difficulty in enriching nutrients required by the microbial population (Moreno et al., 2010; Hwang et al., 2007). Moreover, each air stream varies in terms of its composition, temperature, relative humidity and emission frequency; hence, certain open type biofilters are inefficient in treating emissions containing compounds that are: difficult to biodegrade (e.g. large molecules, xenobiotics); poorly soluble in water; byproducts of biodegradation process such as acidic products (e.g., sulphur and nitrogen compounds) and those resulting in build-up of intermediates like catechols, acetic acid etc. (Rappert and Muller, 2005). Furthermore, other drawbacks of the open system are frequent replacement of the organic media and huge consumption of space. Due to the obscurity of conventional designs of open system biofilters with respect to design and material, the

closed type industrial-scale biofilters have made their way in being equally simple in operation with an ease to regulate the reaction parameters.

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). As the waste gas passes through, 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. Such biofilters up to 6000 meters in wetted area can filter up to 3000 m³/min of waste air (Bajpai et al., 1999). Some closed type biofilters have longevity of 5 years and benefit of being used as fertilizer unless they are potentially hazardous. Multistage biofilters are one of its types that filter waste gas containing different components and require different conditions for microbial treatment. In recent years, there has been a lot of

advancement in biofiltration technology that makes it easier to model a biological filtration process and ultimately design the suitable biofilter. The designing of the biofilter depends on the type of waste gas and its components, required reaction conditions, microbial culture, reactor configuration and other such prerequisites.

Configuration of packing material in biofilter

Selection of the packing material for the biofilter is a very significant task. The packing material is assessed by considering the structure, void fraction, area per unit volume, specific flow resistance, moisture holding capacity, and operating life (McNevin and Barford, 2000). The packing material used for conventional open type biofilters are soil, compost, peat moss, leaves, wood bark etc. with amendments of wood chips, saw dust, sand, bagasse etc. and additives such as limestone (Chung, 2007; Bajpai et al., 1999). Being natural and readily available, they are referred to as biomedica (Xie et al., 2009). The aforementioned amendments enhance the aeration and limestone addition maintains the optimum pH in the system (McNevin and Barford, 2000). The purpose of using such biomedica as packing material is because they house a large variety of indigenous microorganisms by serving as a physical support and source of nutrients.

Usage of compost has a drawback of ageing (due to loss of moisture and different temperature gradients in the filter bed) and is prone to clogging, channelling and creating a high pressure drop over long-term operation which decreases the effectiveness of the biofilter (Abumaizar et al., 1998; Leson and Winer, 1991). During conditions of high pressure drop an immediate replacement is required because there is a compaction in the packing bed (Bajpai et al., 1999). Pressure drop is directly proportional to the packing height. Peat overrules this limitation due to its fibrous structure that makes it more permeable with a lower pressure drop (Hirai et al., 1990). Soil, peat and compost contain certain amount of humic acid which contribute to ion exchange capacity on the solid surface of the packing bed. In order to prevent this and enhance their value, they require pretreatment like conditioning with limestone to reduce their acidity for microbial proliferation (McNevin and Barford, 2000). Nevertheless, localized microbial activity within the filter bed often leads to development of different temperature gradients. The regions of microbial residence have a higher temperature and lower moisture content due to their metabolism, thus making the biologically active sites in the bed dry up and crack faster than the dormant zones (Bajpai et al., 1999).

To overcome these limitations, different porous substances have been used for packing the biofilter beds

along with different combinations of the conventional packing materials. Some of these advanced packing materials used are activated carbon, waste straw, cortex, pall ring, structured ceramic media, peat and perlite, sandstone, clay, textile (technical fabric), polyurethane foam, Bioton (compost with polystyrene spheres and limestone), sintered diatomaceous earth (diatomite) and sugarcane bagasse (Saravanan et al., 2010; Xie et al., 2009; Jorio et al., 2000; Bajpai et al., 1999). The amendments used for these materials are rock, sand, ceramic saddles, charcoal, kaolin, bentonite, anthracite etc. Structured ceramic media checks the microbial biomass by effectively flushing the extra biomass from the biofilter media (Eisenring, 1997). Despite being advantageous in terms of low head loss, large specific surface area and excellent solid phase adsorption of pollutants, the high investment and regeneration cost of pall rings, activated carbon and polyurethane foam limits their regular usage (Martin et al., 2002).

Microorganisms used in biofiltration

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. Sometimes, a single microorganism is enough to degrade the pollutant and sometimes a consortium of microorganisms is used for catabolism. Some biological conversions occurring during biofiltration of odorous compounds are shown in Table 1.

Over the past few years, there has been extensive research on the versatility of the microorganisms employed in biofiltration. Diverse microbial communities such as bacteria, actinomycetes and fungi are involved in biofiltration as they are indigenous to the biomedica such as soil and compost. Much of the research has been focused on bacteria; however, fungi have also been exploited in biofiltration (Spigno et al., 2003; Garcia-Pena et al., 2001; Cox et al., 1997).

Compost has been reported to house bacteria belonging to group *Proteobacteria*, *Actinobacteria*, *Bacteroidetes* and *Firmicutes* (Chung, 2007). Table 2 summarizes a few essential microorganisms and their consortium used in biofiltration to remove the odorous pollutants from waste gases. An efficient biofiltration always depends on its heterotrophic microbial population that use organic compounds as energy and carbon source (Bajpai et al., 1999). A major benefit of the biofiltration system is that the viability of the microorganisms is maintained for a longer period although the system is not in function for a longer period. This is because of using natural materials as the filter bed (Ottengraph and Van Den Oever, 1983).

Although restricted information is available on the microbial communities involved in biofiltration of odorous

Table 1. Bacterial conversions in biofiltration

Bioconversion	Nature of bacteria	Condition
Organic carbon oxidation VOC → CO ₂ , H ₂ O	Chemoheterotrophic bacteria	Aerobic
Nitrification NH ₄ ⁺ → NO ₂ ⁻ , NO ₃ ⁻	Nitrifying bacteria	Aerobic
Sulphide oxidation H ₂ S → S ⁰ , SO ₄ ²⁻	Sulphur-oxidizing bacteria	Aerobic
Denitrification NO ₃ ⁻ → N ₂	Denitrifying bacteria	Anaerobic

Source: McNevin and Barford (2000)

Table 2. Microorganisms used in biofiltration of waste gases

Compound	Odour	Microorganisms
Dimethyl trisulphide	Decayed cabbage	<i>Pseudonocardia asaccharolytica</i> DSM 44247
Dimethyl disulphide	Decayed cabbage	<i>Pseudonocardia asaccharolytica</i> DSM 44247, <i>Hyphomicrobium</i> spp., <i>Thiobacillus</i> spp., <i>Thiobacillus thioparus</i> TK-m
Dimethyl sulphide	Decayed cabbage	<i>Pseudonocardia asaccharolytica</i> DSM 44247, <i>Hyphomicrobium</i> spp., <i>Thiobacillus</i> spp., <i>Thiobacillus thioparus</i> TK-m, <i>Thiocapsa roseopersicina</i> , <i>Pseudomonas putida</i> DS1
Methanethiol	Decayed cabbage	<i>Hyphomicrobium</i> spp., <i>Thiobacillus</i> spp., <i>Thiobacillus thioparus</i> TK-m
Carbon disulphide	Decayed pumpkin	<i>Paracoccus denitrificans</i> , <i>Thiobacillus</i> sp.
Hydrogen sulphide	Rotten eggs	<i>Bacillus cereus</i> var. <i>mycoides</i> , <i>Streptomyces</i> spp., <i>Hyphomicrobium</i> spp., <i>Thiobacillus</i> spp., <i>Thiobacillus thioparus</i> TK-m, <i>Xanthomonas</i> spp., <i>Methylophaga sulfidovorans</i> , <i>Pseudomonas putida</i>
Dimethylamine	Putrid, fishy	<i>Arthrobacter</i> sp., <i>Bacillus</i> sp., <i>Hyphomicrobium</i> sp., <i>Methylobacterium</i> sp., <i>Psuedomonas aminovorans</i> , <i>Mycobacterium</i> sp., <i>Paracoccus denitrificans</i> , <i>Methylophilus methylosporus</i> , <i>Micrococcus</i> sp., <i>Pseudomonas</i> sp., <i>Paracoccus</i> sp. T231
Trimethylamine	Ammonical, fishy	<i>Aminobacter aminovorans</i> , <i>Paracoccus</i> sp. T231, <i>Paracoccus aminovorans</i> , <i>Pseudomonas aminovorans</i> , <i>Hyphomicrobium</i> sp., <i>Micrococcus</i> sp.
Diethylamine	Ammonical, fishy	<i>Pseudomonas citronellolis</i> RA1, <i>Mycobacterium diernhoferi</i> RA2, <i>Hyphomicrobium</i> sp., <i>Pseudomonas</i> sp., <i>Candida utilis</i> , <i>Hansenula polymorpha</i>
Triethylamine	Ammonical, fishy	<i>Pseudomonas citronellolis</i> RA1, <i>Mycobacterium diernhoferi</i> RA2
Various VOCs	Malodorous	<i>Actinomyces globisporus</i> , <i>Penicillium</i> sp., <i>Cephalosporium</i> sp., <i>Mucor</i> sp., <i>Micromonospora albus</i> , <i>Micrococcus albus</i> , <i>Ovularia</i> sp.

Source: Rappert and Muller (2005); Bajpai et al. (1999)

compounds, new technologies such as denaturing gradient gel electrophoresis (DGGE), temperature gradient gel electrophoresis (TGGE) and single strand conformation polymorphism (SSCP) have allowed better understanding of the microbial population dynamics in the natural and artificial systems (Xie et al., 2009; Chung, 2007).

Considerations for an effective biofiltration

The performance of the biofilter is dependent on various

factors, a few of which are discussed here. The nature of the filter media is of great priority. Filter media influences microbial growth and pollutant adsorption as the pollutants have to be adsorbed on the filter media to be available for biological transformations (Xie et al., 2009). For effective operation and prevent filter clogging, dusts, aerosols, grease, resins, accumulated products such as sulphate etc. should be frequently removed by separators (Bajpai et al., 1999). The waste gases sometimes contain certain constituents that make microorganisms vulnerable to them; however, this is avoided by installation of particulate filter before subjecting the gas to biofilter

(Leson and Winer, 1991). Pollutant concentration and pollutant loading rates also affect the biofilter performance. An air stream with high pollutant concentration should be diluted with fresh air in order to increase oxygen concentration required by microorganisms packed in the carrier material (Yang and Allen, 1994). Proper moisture level (usually 40–60%) and temperature (10–15°C higher than ambient) should be maintained within the biofilter (Bajpai et al., 1999). With an increase in temperature efficiency increases and vice versa. The optimum temperature range for H₂S removal is 35–50°C (Bajpai et al., 1999). Very often, there is a gradual increase in temperature due to microbial respiration and exothermic reactions in the filter. Maintaining an optimum pH within the system solely depends on the microorganism used. Yang and Allen (1994) reported higher pH to enhance the removal of H₂S. However, sulphur-oxidizing bacteria have a wide pH range of 1–8. As discussed before, addition of limestone can optimize the required pH range.

CONCLUSION

In recent years, there has been significant progress in biological treatment of waste gases which has resulted in development of biofilters with efficient performance and operation. Biofiltration technology is advantageous in being environmental friendly; inexpensive; having low maintenance cost and higher self-life; efficient at ambient atmospheric conditions of temperature, pressure, pH, moisture and oxygen requirement. Biofiltration has proved to be a valuable alternative to the physiochemical treatment systems in odour abatement in both developed and developing countries.

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