1. Introduction

1.1 Air Pollution

Environmental regulations need the control of volatile organic compounds (VOCs),hazardous air pollutants (HAPs) and odorous organic compounds present in theair. Volatile organic compounds (VOCs) are normally in the liquid state at the ambient condition and have very high vapour pressure or vaporize very easily even at low temperature.VOCs may have harmful effects on human health. The ability of VOCs to cause health effects to human body depend on its toxicity. Some of theVOCs are categorized in the list of carcinogenic compounds.The extent of health effects depends on thelevel of exposure and length of time exposed.Business activities using organic solventssuch as thepainting of wallis amajor source of VOCs emissions.Many common air pollutants, their sources and abundance are listed in Table 1.1.

Hazardous Air Pollutants (HAPs) by the United State Environmental Protection Agency (US EPA) list most of the VOCs. Acetylene, Olefins, heterogeneous ring compounds, aliphatic oxygenated compounds, alcohols, Organic peroxides etc. comes under theclassification of VOCs.A typical list of VOCs is shown in Table 1.2.

Volatile organic compounds are primarily used in paint thinners, lacquer thinners, air fresheners, hobby supplies, wood preservatives, aerosol sprays, degreasers, automotive products, and dry cleaning fluids.

Emissions of VOCs are mainly due to loading and unloading of storage vessels, leakage from pipelines, venting from process vessels etc. Formation of the tropospheric ozone is due to the emissions of volatile organic compounds (VOCs) in the atmosphere. This ozone may be harmful to ahuman being, vegetation, forests and crops etc. Irritations of the throat and eyes, as

well as respiratory difficulties, are some major result seen in human being exposed with ahigher level of VOCs. Tropospheric ozone is regarded as a greenhouse gas.

Table1.1: The most common Air pollutants, their major sources and abundance(in tonsx100) [Source: Perry.2000]

Source Category	Particulate (PM-10)	Sulphur Dioxide	NOx	VOC_S	CO
• Electric utility	270	15836	7782	36	322
• Industrial	219	2830	3176	271	667
• Chemical & Allied product	75	450	414	1811	1998
• Metal processing	141	580	82	74	2091
• Petroleum &related industries	26	409	95	720	398
• Other industrial process	311	413	314	486	732
• Solvent utilization	2	1	3	6249	2
• Storage &Transport	55	5	3	1861	56
• Waste disposal &recycling	248	37	84	2271	1732
• Highway vehicle	197	438	7437	6094	59989
• Off—highway	395	278	2986	2207	15272
• Natural resources-wind erosion	628				

Table 1.2: Typical list of VOCs [Source-Health Canada (www.hc-sc.gc/ewh-smet)]

Acetone	Acetic acid	Ammonia
Alachlor	Benzene	Butanone
Bromodichloromethane	Bromoform	Carbofuran
Carbon tetrachloride	Chlorobenzene	Chloroform
Chlorophenol	Chloropicrin	1,1-Dichloroethylene
Dibromochloromethane(TTHM)	Dibromochloropropane(DBCP)	o-Dichlorobenzene
p-Dichlorobenzene	1,2-Dichloroethane	1,2-Dichloropropane
Cis-1,2-Dichloroethylene	Trans-1,2-Dichloroethylene Dimethyl sulphide (DMS)	Endrin
Cis-1,3-Dichloropropylene	Dinoseb	Ethylbenzene
Ethyl mercaptan	Ethylene Dibromide (EDB) Haloacetonitriles (HAN) Bromochloroacetonitrile, Dibromoacatonitrile Dichloroacetonitrile Trichloroacetonitrile	Ethylene dichloride
Heptachlor Epoxide	Hexachlorobutadiene	Heptachlor
Hexachlorocyclopentadiene	Isoprene	Lindane
Methoxychlor	Methyl mercaptan	Methyl tert-butyl ether
Methyl mercaptan	Pentachlorophenol	Phenol
Pyridine	Simazine	Styrene
2,4,5-TP(Silvex)	Tribromoacetic acid	1,1,2-Trichloroethane
1,2,4-Trichlorobenzene	1,1,1-Trichloroethane	Trimethyl amine
Toluene	Tetrahydrofuran	Trichloroethylene
1,1,2,2-Tetrachloroethane	Trihalomethanes	Tetrachloroethylene
Xylenes(total)		

1.2 Conventional Technologies for VOCs Control and their Limitations

In the conventional VOCs control technologies, thermal incineration and adsorption have been proved to be effective at lower emissions.Incineration is one of the well-knownmethods of industrial gas waste treatment.Incineration is a method which destroys thecombustible organic compoundsin the waste gas rather than collecting it. Providing proper engineeringdesign anygaseous organicstream can be incinerated safely. Catalytic Oxidation has the disadvantage of deactivation and poisoning.In another conventional technology which is called condensation the removal of VOCs occurs at low temperature therefore, this technology is expensive because of therequirement of chilies/condensers.

1.3 VOCs Control by Biological Process

Removal of volatile organic compounds (VOCs), hazardous air pollutants (HAPs) and odorous organic compounds present in air from low to moderate concentrations through biological processes are becoming popular because of theeconomical point of view and minimum production of by-products. However, Industrial scale application started recently.Biofilters, biotrickling filters, and bioscrubbers are the three devices used for this purpose. The main feature of this technology is its ability to convert pollutants to inert products such as CO_2 and H_2O. Biofilters, biotricklingfiltres, bioscrubbers and membrane bioreactors are the control devices in which VOCs and HAZPs are biologically degraded by microorganisms to products like CO_2, H_2O and biomass.

1.3.1 Biofiltration Technology

For the removal of low to moderate concentrations gas streams biofiltration has been emerged as an attractive alternative choice because of its relatively moderate operating costs and minimum byproduct generation.Biofiltration involves naturally occurring microorganisms

attached in the form of a biofilm on a porous medium such as compost,wood charcoal etc. It is also an environmentally friendly technology.

In the biofiltration process, whenVOCs are forced to pass through the packed column containing naturally occurring microorganisms immobilized in the form of a biofilm attached to a porous support medium they get dissolved into wet biofilm and microorganisms present in wet biofilm degrade the pollutants into CO_2, H_2O, intermediate metabolites and biomass. The solubilityof the various air pollutantsplay amajor role in the biodegradation process and It depends on Henry's law constant (H). Pollutants with large H are difficult to soluble in the biofilm as compared to those with small H.In general,Organicchemicals are used by microorganisms as carbon source and overall reaction which is exothermic in nature is expressed as follows;

$$\textbf{Organic pollutants} + \textbf{O}_2 \xrightarrow{\textbf{Microorganism}} \textbf{H}_2\textbf{O}+\textbf{CO}_2 + \textbf{Biomass}$$

There are two biofilterdesigns used for VOCsremoval. The open design biofilters and close design biofilters. The open design biofilters are with rising gas flows and are installed outside the VOC-generatingunits. They require large installation area. The close design biofilters are with either rising are falling gas flows and are installed in closed rooms. Theinstallation areas for such type of biofilters are less as compared to open design biofilters (Mudliar*et al.,* 2010).A schematic diagram of a typical biofilter is presented in Fig1.1.Upto date, industries like petrochemical, pharmaceutical, oil and gas, agrochemical and paint,resins,ink manufacturing industries, waste water treatment plant etc.are using biofilters for pollution control. Typical ranges of various operational parameters for a biofilter are given in Table 1.3.

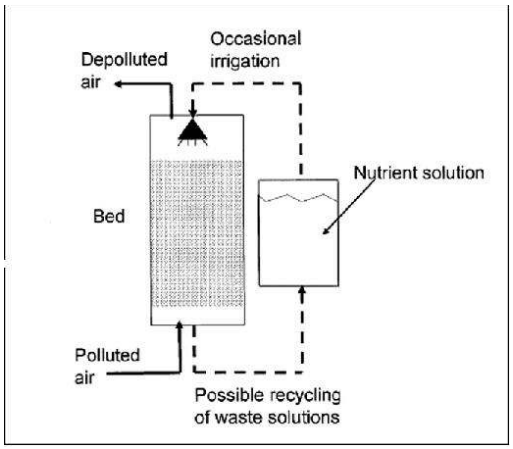

Fig.1.1: A schematic diagram of a typical biofilter (Source: Mudliar*et al.,* 2010).

Principle and applicability of biofiltration for awide range of VOCs; their history and current status of biofilterswere discussed by Leson and Winer (1991). The research done by Neil and Loehr (2000) compared the performance of a typical compost biofilter to a suspended-growth reactor for the biofiltration of toluene from gas streams. A detailed discussion about thedesign of biofilters has been presented in theliterature by Smet*et al.*, (1998). A review about the biofilters that are used in VOC and odour removal along with details on their configuration and design and operation has been reported by Mudliar*et.al*.,2010.

1.3.2 VOCs Control by BiotricklingFilters

Supply of nutrients and the contaminated air in biotrickling filter is from the top of the bed of the filter material but in case of biofilter the supply of the contaminated air is from the bottom of the bed of the filter material and also supply of nutrients to the filter material in biotrickling filter is continuous but in case of biofilter it is occasional. So, the operating cost of the biofilter is less than abiotrickiling filter.

1.3.3 VOCs Control by Bioscrubbers

In bioscrubber, absorption occurs in one stage and removal of VOCs occurs in another stage. Hence, it is a two stage process. Microbes are suspended in the second stage where removal of VOCs occurs. Formation of excess sludge is the main limitation of this technology.

1.3.4 VOCs Control by Membrane Bioreactors

This is an alternative biological treatment method for the treatment of waste gas. The transfer of VOCs from gas to liquid phase containing microbes is through pores in the hollow fibermembranes. No moving parts, easy operability, no occurrence of flooding and loading etc. are some salient features of this technology. High installation cost is the major drawback of this technology. Table 1.4 shows main technical characteristics of biological treatment methods.

Table 1.3: Main technical characteristics of biological treatment methods (Source: Delhomenie and Heitz, 2005)

Bioprocess	**Microorganisms**	**Liquid Phase**	**Depollution step**
Bioscrubbers	Suspended in the bioreactor, in the aqueous growth medium	• Mobile • Continuous dispersed • Recycle	• VOCs/Air separation within the absorption column • VOCs oxidation in the aerated bioreactor
Biotrickling filter	Immobilized material	• Mobile • Continuos trickling over the filter bed • Possible recycle	• In the filter bed • In the biofilm
Biofilter	Immobilized material	• Occasional bed irrigation with nutrient solution	• In the filter bed • In the biofilm

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