2. Literature Survey

Biofiltration is a cost effective and environmental friendly technology and has potential to treat contaminated air stream polluted with low to moderate concentration.Although a lot of work has already been done by various researchers on biofiltration yet there is scope for improvement from commercial application point of view of this process. The initial research attempts by various researchers were mainly focused on establishing the fact of biodegradation of pollutants in the biofilters. After well establishing above fact the further research work were mainly focused on improvement of biofilter by optimizing various process parameters, selection of biofilter media, improvement in the desirable properties of material from biofilteration point of view by physicomemical changes, selection of suitable microorganism for effective degradation of pollutant, analysis of metabolites or intermediate products during biofiltration , study of kinetics of biofiltration process and development of mathematical model of the biofilters.

A detail literature survey on biofiltration is given in the subsequent sections.

2.1 Parameters which affect the performance of any biofilter

2.1.1 Pollutant affection with water

The solubility of the pollutant in the water governs the performance of any biofilter because the adsorption of the pollutant on the wet biofilm is dependent on their solubility. The rate of dissolution is expressed in terms of Henry's law constant (H). Pollutants with large H are difficult to dissolve than those with small H. After dissolution in the water the pollutants must be degraded as soon as possible because higher concentration may increase to levels that are toxic to the microorganism. Alcohols, aldehydes, aromatics (BTX compounds), Ethers, Esters, Organic acids, Amines etc. are highly water soluble. Table 1.4 shows biodegradability of different gases.

Table 1.4: Biodegradability of different gases.

Rapidly degrading VOCs	Rapidly reactive VOCs	Slowly degradable VOCs	Very slow degradable VOCs
Alcohols	H_2S	Hydrocarbons	Halogenated Hydrocarbons
Aldehydes	NOx(excluding N_2O)	Phenols	Polyaromatic hydrocarbons
Ketones	SO_2	Methyl chloride	CS_2
Ethers	HCL	--	--
Esters	NH_3	--	--
Organic acids	PH_3	--	--
Amines	SiH_4	--	--
Thiols	HF	--	--

2.1.2 Packing Media

Packing media play very important role in the biofiltration process because they act as support and also provide the desirable environment for the growth of microorganisms. A variety of materials including compost, agro-wastes, coal, wood charcoal, peat, polyurethane foam and modified materials have been used for biofiltration process with their advantages and limitations. The materials used as asupport medium in the biofiltration operation are divided into the two broad categories – Natural media and Synthetic media. Normally the natural material provides theoptimum environment for theformation of thestable film and consequently support the growth of microorganism but lack in physical strength and hence durability. On other side, the synthetic materials such as polyurethane foam provide excellent strength and durability but thesurface of these materials are less microbe-friendly as compared to their natural counterpart. The optimal filter material should have the following characteristics: high moisture holding capacity, porosity, available nutrients and pH buffer capacity (Deviney*et al*., 1999). A brief description of different types of materials that have been used in the biofiltersis given in the subsequent section.Natural packing media include compost, peat, bark, wood chip and coal etc. Synthetic packing materials include plastic Pall Rings, activated carbon (GAC), polyurethane foam etc.

2.1.2.1 Natural Packing Media

A variety of natural packing media has been reported in the literature. The most widely used media are compost, peat, bark, different types of agrowaste, wood chips, and soil etc. These materials possess many of qualities such as large specific area, larger water retention capacity, low bulk density ease of availability, low cost,theand thepresence of nutrients with the main drawback of medium compaction.Some natural materials such as peat, soil, compost have been demonstrated as excellent biofilter media because they provide theoptimum environment.with time are some Medium compactness and deterioration major problems associated with the natural packing medium.

2.1.2.1.1 Compost

Compost has been widely used by the researchers due to its cost effectiveness, inherent availability of micro and macro nutrient and presence of abroad spectrum of themicrobial population so inoculation is not required. Industrial sludge, animal waste, animal manure, food and agricultural residues are the major raw material used for the production of compost. Many researchers used compost as packing media in their biofiltration studies (Delhomenie*et al.,* 2002; Liu *et al.,* 2002; Namkoong*et al.,* 2003; Wu *et al*., 2006).

2.1.2.1.2 Peat

Peat is an acidic material with high surface area.Moisture control is one problem associated with it and also nutrient and buffering is required during operation.More than 90% removal efficiency was observed in the biofiltration study using peat as packing media done by Elmrini*et al.,*(2004).

2.1.2.1.3 Agro waste

From acost point of view, agricultural waste is a good choice for biofilter packing. Sugar cane bagasse, peanut shell, rice husk, coconut shells, maize cobs, yellow gram stalk are some commonly used agro waste used as packing media in biofiltration study (Lopez *et al*., 2003; Singh e*t al*., 2006).Sugarcane bagasse has been used by Mathur*et al.,* (2007) for their study on biofiltration.

2.1.2.1.4 Coal

Coal is another natural packing media which is used by many researchers for their biofiltration study (Mathur*et al.,* 2006; Mathur*et al.,* 2008; Lu *et al.,* 2000). Coal also has Shukla*et al.,* (2009) used coal in their biofiltration study for the degradation of the very toxic and sparingly water soluble compound TCE and got maximum elimination capacity of about 5.31 $gm^{-1}hr^{-1}$at an inlet load of greater than 7.90 $gm^{-1}hr^{-1}$.

2.1.2.1.5 Soil

The presence of microbial population and its lower cost make soil good choice for biofiltration media.High pressure drop and solubility in water are the problems associated with this packing media. Biodegradation of styrene using soil was studied by Kenji *et al., (*2003) and they got removal efficiency more than 70%.Lava rock or sand was used by Steel *et al., (*2005) for the ethanol biodegradation and they got removal efficiency of around 80%.

2.1.2.2 Synthetic / Inert Packing Media

To overcome the various weaknesses of natural media such as medium compaction, strength, durability etc.in the biofilteroperation, man-made materials such as PU foam, Pall rings etc. has been widely tested aspacking media for the biofiltrationstudies. Low pressure drop, longer life, thelarger specific area makes these materials better than natural packing media. Although need of inoculation and long acclimation period are the disadvantages of these materials. The needfor anexternal supply of nutrients during biofiltration operation is also one major problem. Some of the important and widely used synthetic materials used as biofilter media have been discussed in the following section.

2.1.2.2.1 Granular Activated Carbon (GAC)

GAC is very good adsorbent, have high porosity and larger surface area that is why is it used by many researchers for their biofiltration studies in the recent years (Abumaizer*et al.,* 1998; Ho *et al*., 2008).Ho *et al*., (2008) used it for their biofiltration study for the removal of sulphur compounds and they get removal efficiency more than 95%.

2.1.2.2.2 PU Foam

Singh *et al*., (2010);Qi and Moe, 2006used successfully PU foam for their biodegradation studies. Less aging, good strength, alarge surface area some major features of these materials. Biomass removal is easy in case of clogging problem when PU foam are used as packing media.

2.1.2.2.3 Pall Ring

Stability, lowcost and high porosity make pall rings suitable media for bio filtration (Oh and Choi, 2000).Pedersen and Arvin; 1995; Schonduve*etal* (1996); Kim *et al.,*(2007) used successfully pall rings for their biofiltration study and they got good results. Low specific surface area and poor biofilm attachment are the major drawbacks of these packings.

2.1.2.3 Composite Media

Preparation and application of composite material for biofiltration process is therelatively new area. The composite materials are prepared such a way that it should possess the required desirable properties of natural as well as synthetic materials for successful biofilter operation. Composite packing materials provide afavorable surface for attachment of biofilm, are mechanically strong and durable. There is no need to supply nutrients to the microorganisms because it is added in the packing media during the preparation of such packing materials. Physico-chemical properties of the synthetic materials such as porosity, surface area, buffer capacity and water retention capacity can also be improved when they are chemically modified(Hirai*et al.,*2001).

2.1.2.3.1 PVA/Peat/KNO_3

Chan and Lu., 2003 used peat as the base material and the bonding agent PVA to prepare PVA/Peat/KNO_3 composite media.In order to supply nitrogen to the microbes, KNO_3 and phosphate were added to increase the stress strength of the composite media.Removal efficiency more than 95% was observed when this packing media was used for biodegradation of ethyl acetate.

2.1.2.3.2 PVA/Peat/KNO3/GAC

Adsorption capacity, moisture holding capacity and porosity were improved when GAC was added with PVA/Peat/KNO3/GAC in the work done by Chan and Su (2008).Also; the microbial growth rate for ethyl acetate biodegradation was found higher. Chan and Peng (2008)used this composite material for their biodegradation kinetic study of acetone, methyl ethyl ketone, methyl isobutyl ketone and methyl isopropyl ketone. Elimination capacity of acetone was found to be maximum.

Composite filter material has better physicochemical properties such as porosity, surface area, buffer capacity and water retention capacity, p^H buffer capacity over other materials.N,P,K are added during manufacturing of these materials to overcome the drawback of theabsence of macro and micro-nutrients.

2.1.3 Temperature

There is a conflict over increasing the biofilter temperature. Rates of reaction and diffusion will increase for higher temperatures. However, the water solubilities of VOCs and sorption capacity of filter solid will decrease. Metabolism of the microbes is strongly affected by temperature.Formesophilicmicroorganisms, the optimal temperature range is in general 15-40^{0}C.Devinny *et al.,*(1999) found that the metabolic rate of thermophilic bacteria can be enhanced by increasing temperature.Increased removal efficiency and elimination capacity are obtained due to increased metabolic activity.Increase in temperature from 23 to 26.6^{0}C was observed by increasing tolueneconcentration in a biofiltration study made by Delhomenie*et al.,*(2002) due to speed-up of biological action. Park *et al.,* (2002) found that maximum removal of H_2S was in the range of 30-35^{0}C.Matteau *et al.,* (1999) found that compost thermo philicbio filtration was much effective at higher concentrations of toluene.

2.1.4 Moisture Content

Biofilter medium moisture content is an important parameter in biofilteroperation.Anover wet biofilter medium causes highbackpressure and low gas retention time due to theblockingof the pores with water. Anaerobic zones are also created that promote slow degradation rates.In thecase of a dry filter, medium microorganisms shall get deactivated. Optimalbiofilter medium moisture contents range from 40 to 60% (wet weight). Proper water addition requires careful planning and knowledge of the medium moisture content.For optimal growth of microorganisms minimum water content is required(Ottengraf., 1986).Effect of water content on biodegradation rates of ethanol using peat as biofilter media was studied byAuria*et al.,*(1998).After reducing the moisture content the packing material elimination capacity dropped.Morales*et al.,(*2003) shown that excess water causes areduction in biofilter porosity.

2.1.5 p^H Value

A specific pH range is required for most of the microorganism for the biodegradation. The performance of the biofiltration is strongly dependent on pH. As for most aerobic biological processes, the optimal pH for biofilter operation is in the range of 7 to 8.Most of the microorganism prefer neutral environment because acidic conditions inhibit microbial activity. Qi and Moe, 2006 reported that in low p^H fungi were dominating species.Variation in p^H from 6.5 to 8 was noted in the biofiltration study as toluene as target compounds and using compost and sea shell as packing media by Fernandez *et al., (*2007).A variation of 8.8 -7.2 of pHrange was noted in a biofiltration experiment done by Singh *et al*., (2010) using PU foam as packing media and toluene as target pollutant.Similar behavior was observed by Lim (2005), Dorado *et al.,* (2008), and Singh *et al.,* (2006).Formation of carbonic acid in the biofilter during biodegradation may be responsible for thedecrease in pH.

2.1.6 Nutrients Supply

Pollutant elimination capacity is maximized by providing nutrients in sufficient quantity to the microorganisms. It should match the elemental composition of biomass. Organic media, such as compost, usually supply ample quantities of nutrients in the available form. However, nutrient availability can be of concern in some situations. The issue of nutrient availability and nutrients addition is important in biofilter design and operation yet there is no guideline presently developed to identify the amount of available nutrients needed in biofilters. It is necessary to provide nutrients to biofilter operating with inert media like GAC.Behaviour of biofilter in various nutrients compositions has been studied by Heitz*et al.,* (1997) and they found that decrease in removal efficiency due tohigh gas flow rate can be recovered by supplying higher supply of nutrients.VOCs removal efficiency has been increased by adding available nitrogen nutrients into the packing media like compost and wood bark in the biofiltration study made by Morgenroth*et al.,* (1996).

2.1.7 Pressure Drop

The increase in pressure drop requires more power consumption therefore from aneconomical point of view, it should be minimized.The pressure drop across the bed depends on media pore size, moisture content, media porosity, bed depth and gas flowrate.Pressure drop ranges from1-10 kPa for a typical biofilterunit. Irrigation of biofilter increases thepressure drop across the biofilter media (Bagherpour*et al.,*2005).A maximum pressure drop of 0.17 cm H_2O per meter of biofilter column at flow rate of 1 m^3hr^{-1} and at toluene concentration1.7 $gm^{-3}$was found by Delhomenie*et al.,(*2002).In a compost bed treating toluene a pressure drop of around 204 mm of H_2O per meter was noted by Fernandez *et al.,(*2007).Kennnes and Thalaso.,1998 reported that among the organic packing media soil gives rise to highest pressure drop followed by composts,then peat and wood chips.Bed pressure drop can be minimized by the addition of inert spheres to the natural organic media(Jin *et al.,*2005).

2.1.8 Gas Flow Rate

The amount of pollutant entering the biofiltrationunit in unit time is known as gas flow rate. The mass transfer rate through the biofilm is increased if the gas flow rate is increased. Residence time is also decreased by increasing gas flow rate.Biofiltration of single and mixed benzene, toluene, ethylbenzene and xylene vapours was carried by Lu *et al.,(* 2000) in a trickle bed biofilter.Biofiltration of butyl acetate by a trickle bed bioreactor was studied by Lu *et al.,*(2004) under varying concentrations and gas flow rate.Delhomenie*et al.,*(200)reported removal efficiency of more than 90% at EBRT of 165 s and maximum elimination capacity of 55 $gm^{-3}hr^{-1}$ for inlet loads equal to or greater than 65 $gm^{-3}hr^{-1}$.Using compost-activated carbon media Abumaizar*et al.,*(1998) reported 90% removal efficiency at inlet concentration of around 200 ppm for BTEX.Galera*et al.,(*2008) studied using rock wool-compost media in two columns and observed the effect of pollutant concentration ratio on the simultaneous degradation of NH_3,H_2S and toluene gases and found thebad effect of toluene removal due to high loading of H_2S.A removal efficiency of 98% at an inlet concentration of 0.2 g m^{-3} was obtained in a biofiltration study made by Saravanan and Rajamohan.,2009 using press mud packed as packing media and xylene as target compound.

2.1.9 Kinetic Model

Many mathematical models have been proposed in theliterature to evaluate the effect of various operating parametersto describe and also to improve the process design and application of the biological treatment systems.Ottengraf' and van den Oever(1983) proposed a model known as zero-order diffusion limitation model which was based on the steady - state plug flow behavior of the contaminants through a bed of solid filter particles coated with a biologically active biofilm.Many researchers used this model for understanding and describing the biofilter performance (Zilli *et at.,*1996).A steady state model assuming first order reaction in the biofilm with respect to both oxygen and methanol was proposed by Shareefdeen*et al.,(*1993).Taking into accountdispersion,convection,adsorption,oxygen limitation,diffusion,biodegradationAmanullah*et al.,(*1999)proposed transient biofiltrationmodel.AssumingMichaelis-Menten or Monod type kinetics and anexcess quantity of oxygen a transient biofiltration model was proposed by Deshusses and Dunn.,1993.Degradation of dichloromethane was modeled by Okkerse*et al.(,*1999) taking into account effect of p^H on biodegradationrate which was controlled by thegeneration of acids and buffering capacity of biofilm.The most commonly used model considering microbial growth is the Monod model.This is a mathematical model for the growth of microorganisms. It has been proposed using an equation to relate microbial growth rates in an aqueous environment to the concentration of a limiting nutrient. The form of the Monod equation is same as the Michaelis–Menten equation only difference is that it is empirical while the latter is based on theoretical assumptions.Many researchers (Ramirez *et al.,*2008; Wani*et al.*,1999;Sologar*et al.,*2003,Hirari*et al.,*1990) used Michaelis–Menten equation in their respective studies to describe macrokinetics of thebiofilter.

Where, C_{in} and C_{out} are the inlet and outlet pollutant concentration, respectively, V is the packed bed volume (m^3) and Q is the airflow rate ($m^3\ h^{-1}$). Experimental data have been used to calculate these parameters.

2.2 Current Status of Work and Objectives of Research work

Biofiltration is one of the most cost effective and clean technology available to treat many contaminated gaseous streams and particularly successful for removal of VOCs and odrous compounds. The technology is gaining popularity because of increasing concentration of gaseous pollutants particularly VOCs in the air.

Removal ofmethyl ethyl ketone (MEK), toluene, *n*-butyl acetate and *o*-xylene (MTBX) emitted from the paint industry was carried out in a coal based biotrickling filter by Majumder and Mathur., 2008.They found 100% removal at MTBX loadings less than 120 $gm^{-3}\ h^{-}1$.A maximum elimination capacity of 184.86 $gm^{-3}\ h^{-1}$ was obtained at an MTBX load of 278.27 $gm^{-3}\ h^{-1}$ with an empty bed residence time of 42.4 s. They concluded that the condition was the most favorable for *n*-butyl acetate degradation followed by MEK, toluene and then *o*-xylene. Removal of amixture of acetone, methyl ethyl ketone, toluene, ethylbenzene, and *p*-xylene has been investigated by Qi and Moe.,2006in two biofilters packed with polyurethane foam operated over 63 days. Total VOCs loading rate in both biofilterswas 80.3 $g\ m^{-3}\ h^{-1}$. One biofilter was operated under continuous loading conditions and the other under intermittent loading conditions operated only for 8 h/day. Overall removal efficiency in both the biofilter were 97–99% and 90% respectively. In both the biofilters, ketone components were more rapidly degraded than aromatic components. Biodegradation of methyl ethyl ketone (MEK) was studied in a lab scale biofilter packed with amixture of coal and matured compost by Raguvanshi and Babu., 2009 and they got maximum removal efficiency of 95%.In the study made by Chan and Peng.,2009 the biochemical kinetic behaviors of ketone compounds in a composite bead biofilter were investigated. They concluded that the inhibitive effect was the least pronounced for acetone and the order of microbial growth rate was MEK > MIPK > acetone in the average inlet concentration range of 100–150 ppm.Chan and lai., 2010 done study on compounds interaction on the biodegradation of acetone and methyl ethyl ketone mixture in a composite beadbiofilter.Kiared*et al.,*(1996) concluded around 80 and 70% removal of ethanol and toluene in a biofiltrationstudy.Abumaizar*et al.,(*1998) reported around 90% removal efficiency for BTEX using compost activated carbon filter.Jorio*et al.(*1998) reported that due to thepresence of xylene reduced the removal efficiency of toluene while the presence of toluene had anegligible effect on the removal efficiency of xylene.Many studies have investigated the biofiltration of toluene using various packing material by various researchers(Morales *et al.,* 1994; Sharifdeen and Baltzis, 1994; Smith *et al.,* 1996; Schonduve*et al.,* 1996;Heitz *et al.,*1997;Kinney *et al.*,1998;Darlington *et al.,*2001;Acuna *et al.,*2002;Delhomenie *et al.,*2003;Barona *et al.,*2004;Park *et al.,*2002;Rene *et al.,*2005;Maestre *et al.,*2007;Fernandez *et al.,*2007;Darado *et al.,*2009).

Using the mixture of compost, sugar cane bagasse and granulated activated carbon (GAC Mathur*et al.,* (2007)done a biofiltration study for air stream containing amixture of benzene, toluene, ethylbenzene and *o*-xylene (BTEX) in a lab-scale biofilter. For an inlet concentration of 0.681 gm^{-3}, biofilter achieved maximum removal efficiency more than 99% of all four compounds at an EBRT of 2.3 min. They also concluded that when the influent BTEX loadings were less than 68 gm^{-3} h^{-1} in the biofilter, nearly 100% removal could be achieved. They also found that elimination capacities of BTEX increased with the increase in influent VOC loading, but an opposite trend was observed for the removal efficiency.Morlett-Chavez *et al.,* 2010 studied and evaluated the efficiency of BTEX biodegradation by a consortium acclimatized to unleaded gasoline and bacterial strains isolated from it. The consortium degraded 95% of total BTEX.Biodegradation in vadose zone transport models for benzene, toluene and xylene (BTX) and fuel hydrocarbons has been proposed by Hers *et al.,*(2000). Flow-through column and liquid batch experiments were performed in the biofiltration study done by Kelly *at al., (*2006). They observe biodegradation of benzene, toluene, and xylene under toxic conditions.Maliyekkal*et al.,*(2004) employed microbial consortium acclimatized with benzene, toluene or xylene (BTX) to study the degradation pattern of these compounds individually under aerobic conditionsunder substrate versatility conditions they done abatch and continuous experiments to evaluate the adaptability of the enriched cultures. Toluene degradation was highest, followed by benzene and xylene in the aqueous phase in this study.In the biodegradation study made by Robledo-Ortiz *et al.,*(2011)benzene, toluene, and o-xylene (BTX) degradation by immobilized Pseudomonas putida F1was done. They used Monod equation to model the experimental data obtained from the biodegradation kinetics, and they were adequately described with this model.Lovanh*et al.,*(2002) done chemostat experiments with four pure cultures to determine how ethanol affects benzene, toluene, ethylbenzene, and xylene (BTEX) biodegradation kinetics. In all cases, the presence of ethanol decreased the metabolic flux of toluene. Biodegradation of xylene has been done by many researchers using various packing media(Elmrini*et al.,*2004;Bibeau*et al.*,1998;Jorio*et al.,*2000;Gloria*et al.,*2005;Wu*et al.,*2006).Abumaizar*et al.,* (1998)reported using three laboratory-scale biofilter columns operated for 82 days biofiltration of mixture of benzene, toluene, ethylbenzene, and *o*-xylene (BTEX). A mixtureof yard waste and sludge compost was used as base packing media. Different amounts of granular activated carbon were mixed with the compost in two of the three columns to evaluate the performance of which biofiltercan be increased. The result showed that biodegradation rate was higher of benzene followed by toluene, ethylbenzene, and *o*-xylene, respectively. More than 90% removal efficiencies were achieved for all component in all columns. At increased gas flow rate,biofilters containing GAC showed higher removal efficiencies.

Dehghanzadeh*et al.,* (2005) studied the biofiltration of waste gas styrene vapor in a three-stage bench-scale biofilter. Yard waste compost mixed with plastics was inoculated with activated sludge. Under steady-state conditions, maximum elimination capacity obtained was 45 g m^{-3} h^{-1} at a loading rate of 60 $gm^{-3}h^{-1}$.A decrease in retention time affected the performance resulting in the maximum EC. Jang *et al.,* (2006)studied styrene removal in a biofilterinoculated with a *Pseudomonas* sp. SR-5 and using a mixed packing material of peat and ceramic under the non-sterile condition. More than 86% removal efficiency was obtained in a 62 days operation period. In a three-month operation, in a laboratory-scale biofilter packed with a mixed packing material of peat and ceramic and inoculated with Pseudomonas sp. SR-5 more than 90% removal efficiency (RE) was by biofiltration study done by Jang *et al.,*(2005).Rene *et al.(* 2010) done biofiltration of gas-phase styrene using a fungussporothrixvariecibatusand perlite as packing media.With the variations in loading rates from 50 to 845 g m^{-3} h^{-1}, they got nearly 65% styrene removal. They also find that the critical inlet loads to achieve more than 90% removal were 301, 240 and 92 g m^{-3} h^{-1} for EBRT of 91, 40, and 20 s, respectively. Rene *et al.,* (2010) studied biodegradation performance of a biofilter, inoculated with the fungus Sporothrixvariecibatus, to treat gas-phase styrene and acetone mixtures under steady-state and transient conditions.They concluded that he total elimination capacities were as high as 360 gm^{-3} h^{-1} with 97.5% removal of styrene and 75.6% for acetone. They also find that the biodegradation of acetone was inhibited by the presence of styrene while styrene removal was affected only slightly by the presence of acetone. They also performed periodic microscopic observations and find that the originally inoculated Sporothrix sp. remained present in the reactor and was actively dominant in the biofilm.Zilli*et al., (*2001)used two identical sized laboratory-scale biofilters, filled with the same type of packing material, consisting of a mixture of peat and glass beads in a 4:1 volume ratio to investigate biodegradation of toluene and styrene-containing off-gas streams. One of the biofilters was inoculated with a toluene-degrading strain of *Acinetobacter*sp. NCIMB 9689, and the other with a styrene-degrading strain of *Rhodococcusrhodochrous AL* NCIMB 13259. For both pollutants, different sets of continuous experiments were conducted in the biofilter columns. Maximum elimination capacities of 242 and 63 $gm^{-3}hr^{-1}$ were recorded for toluene and styrene;respectively.Based on their biofiltration study Acosta *et al.,* 2012 checked the performance of perlite and two innovative carriers that consist of polyurethane (PU) chemically modified with starch and polypropylene reinforced with agave fibers against amixture of VOCs composed of hexane, toluene and methyl-ethyl-ketone.Ata total loading rate of 145 $gm^{-3}h^{-1}$the elimination capacities (ECs) obtained were 145g $m^{-3}h^{-1}$, 24g $m^{-3}h^{-1}$ and 96g $m^{-3}h^{-1}$for the biofilterpacked with the PU, the reinforced polypropylene, and perlite, respectively.Chan *et al.*, 2008useda sphericalcomposite bead PVA/peat/KNO3/GAC reported that both microbial growth rate and biochemical reaction rate were inhibited at higher inlet concentration in a biofiltration study for the amyl acetate ethyl acetate. For the microbial growth process, the microbial growth rate of ethyl acetate was greater than that of amyl acetate in the inlet concentration range of 100–400 ppm.

The increase in pressure drop requires more power consumption so it should be minimized.It depends on media pore size, moisture content, media porosity, bed depth and gas flow rate. Pressure drop ranges from 1- 10 kPa for a typical biofilter unit. Irrigation of packing media increases the pressure drop across the biofilter media (Bagherpour*et al.,*2005). Delhomenie*et al.,(*2002) reported a maximum pressure drop of 0.17 cm H_2O per meter of biofilter column at flow rate of 1 m^3hr^{-1} and at toluene concentration of 1.7 gm^{-3} . Fernandez *et al.,(*2007) used compost bed treating toluene and repoeted a pressure drop of around 204 mm of H_2O per meter.Kennnes and Thalaso.,1998 reported that among the organic packing media soil gives rise to highest pressure drop followed by composts, then peat and wood chips.Bed pressure drop can be reduced by the addition of inert spheres to the natural organic media(Jin *et al.,*2005). The main purpose of the filter material is to provide support as well as essential nitrogen and phosphorus to the microorganisms for their growth and metabolism. Packing material properties, such as, high moisture holding capacity, porosity, low bulk density, high surface area, available nutrients and pH buffer capacity, make any filter material novel for the biofiltration. Natural packing material like compost has been used by many researchers for their studies on bio filtration.Synthetic packing materials like plastic Pall rings, activated carbon (GAC) and polyurethane foam have also been used successfully in different biofiltration studies by many researchersFernandez*et al*.,2013;Webber *et al*.,1995;Singh R.S *etal*;2010) Thus both organic and inert materials have been used as filter bed in industrial filtration. However, the former have a relatively low durability (up to a few years), while the latter tend to be expensive and usually require a periodical nutrient supply. Consequently, the efforts are going on for the development of a material comprising the advantages of both organic and inorganic materials.

There are a number of biofiltration studies reported in literature including natural and inert packing media like compost, peat, bark, wood chip, coal, plastic Pall Rings, activated carbon (GAC), polyurethane foam etc. There are certain advantages and disadvantage of each packing media.Biofilter packing media may be categorized as natural, inert or synthetic packing materials.During the long-term operation of biofilter column, natural packing materials like compost, agro waste, peat, soil etc. usually crack causing medium compaction which results in the rise in the bed head loss. In order to compensate such problems, mechanically strong non-biodegradable media like PU-foam, GAC etc. was used by many researchers.Thesematerials are mechanically strong but usually require a periodical nutrient supply during the operation of any biofilter column and also expensive.To overcome the problem of continuous supply of nutrient, few attempts have been made by researchers to develop modified biofilter media(Chan *et al*.,2008;) in which by physicochemical processes the properties of the media were improved and nutrients were also added.

The Modified packing materials may begood option because they are mechanically strong and also there is no need to supply nutrients to the microorganisms because nutrients are added during the preparation of such packing materials. Only few papers are available on durability and performance of modified biofilter media so there is scope for further research in this area.

The literature survey clearly show that biofiltration technology has been used for removal of various VOCs at laboratory sacle. The selection of proper media play an important role in the successful biofilter operation. The major limitation towards application of this technology at industrial scale is durability of biofilter media and continuous supply of the nutrient during the operation.Keeping this fact in mind, present work has been planned with following objectives.

1. To modify the easily available and low cost packing media like wood charcoal and compost (a material commonly used as biofilter media) by adding / adhering the nutrients on its surface using physicochemical techniques.
2. To characterise the modified biofilter media.

3. To evaluate the performance of modified media against common VOCs such as paint solvent mixture(MTX),Petrochemical Mixture(BTX) and Polymer solvent (Styrene) laden air streams.
4. To study the kinetics biodegradation of VOCs in the biofilters.

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