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Biodegradation Of Toluene Using Different Bioreactors – A Review

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Abstract: The rate of polluted gases in the atmosphere comprises of some dissolved organic compounds which affects the environment apparently. This comparative study relies on various types of bio-reactors, which is used to degrade toxic substances. The bioreactors are abundantly used to degrade those substances depending upon various parameters and suitable materials like packing material, microbes, etc. One such compound which is highly toxic to human beings and also present in the gaseous state is Toluene. "Fixed film bio-filter" is vastly superior because of their very high removal efficiency of VOCs and sustainability of microbial use against contaminants in removing them and also durability in their usage.
Key words: Toluene, Biodegradation, Fixed film bio-filter, Health hazards, Bioreactor.

1. Introduction:

Environmental pollution is any discharge of material or energy into water, land, or air that causes or may causes acute (short-term) or chronic (long-term) detriment to the earth's ecological balance or that lowers the quality of life. Pollution can be broadly classified according to the components of environment that are polluted. Majority of these are: Air pollution, water pollution, soil pollution, and noise pollution. The substances that cause pollution are called as pollutants. Earth has been loaded with diverse pollutants that were released as by-products. Pollutants are generally grouped under two classes: Biodegradable pollutants and Non- Biodegradable pollutants[1].

In air pollution, Volatile organic compounds (VOCs) are one of the main components of air pollutants[2] that do not get much attention from researchers. VOCs are organic chemical compounds that have high enough vapor pressures under normal conditions to significantly vaporize and enter the atmosphere. VOCs are among the most common air pollutants linked to industrial process emission and are also considered as the major contributions of indoor air pollution. Some common examples of VOCs include Benzene, Toluene, Ethyl benzene, Xylenes, Formaldehyde and halogenated hydrocarbons[3]. Toluene is one of the major noxious volatile organic compounds that act as a type II carcinogenic agent. The name toluene was derived from the order name toluol, which refers to tolu balsam, which was first secluded from Myroxylon balsamum. It was originally named by johns Jacob Berzelius. Toluene (C_7H_8) is an aromatic hydrocarbon belonging to the BTEX group of hazardous volatile organic compounds; carbon-carbon bond length is with an approximation of 0.1397nmm, these accounts for the stabilization energy of 163.2 KJ/mole[4] and the structure is shown in Fig1.

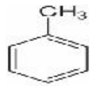

Figure.1. Chemical Structure of Toluene

Toluene is a common solvent, Which can dissolve paints, paint thinner, Silicon sealants etc., Even though toluene possess positive reassuring facet, it also constrain certain environmental and health hazards such as tiredness, confusion, memory loss and nausea, loss of appetite and hearing and color vision loss**.** Thus symptoms usually disappear revelation is stopped. Inhaling high levels of toluene in a short time may cause light-headedness, nausea, or sleepiness. It can also cause unconsciousness, and even death[5].

Toluene is well known for its neurotoxicity and exposure to it may decrease neuronal activities in vitro and cause mental depression and cognitive impairment in humans[6]. Toluene inhalation also results in various symptoms such as fatigue, headache, vertigo and ataxia. It is rapidly absorbed through respiratory and gastrointestinal tracts and to a lesser extent, through the skin. American Conference of Governmental Industrial Hygienists (ACGIH) has recommended an 8-h time-weighted average of 50ppm (189mg/m^3) for toluene to protect against effects on the central nervous system[2]. The removal and destruction of toxic volatile organic compounds from air streams is important for safety as well as environmental reasons. There are number of removal technologies available to treat VOC polluted air stream such as Chemical treatment methods and biological waste gas treatment. Chemical treatment methods such as thermal oxidation and incineration are often too expensive to treat high volume, low concentration sources[7,8]. In Biological waste gas treatment methods, biofiltration has attracted considerable interest in last few years. It is cost effective and very efficient removal process without generating any secondary air pollutants. It is used to eliminate contaminants from air using microorganisms, which are immobilized on a surface of solid support media. This technique has been applied successfully to control the number of air pollutants such as odours, VOCs and hazardous substances[9].

A bioreactor is a vessel in which a chemical process is carried out, which involves organisms or biochemically active substances derived from such organisms. This process can either be aerobic or anaerobic. These bioreactors are commonly cylindrical, ranging in size from litres to cubic metres, and are often made of stainless steel. It consist of an air compressor, oxygen tank, dehumidifier, activated carbon beds, dynamic system for the generation of BTX vapours, foam columns, cell reservoir, deformer and controlling devices[10]. In the field of biochemical engineering, using various types of reactors, including an airlift loop reactor, a bubble column reactor, a stirred tank reactor, and a jet loop reactor etc[11].

Decontaminated air to atmosphere

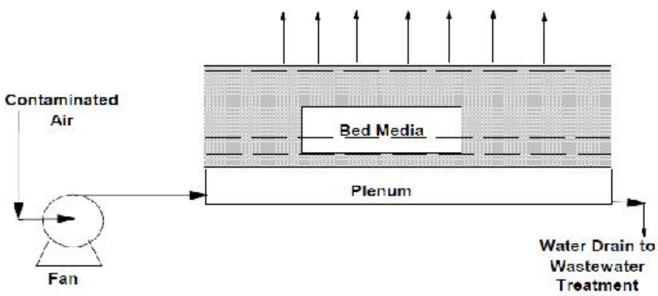

Figure.2. Basic Biofilter

New sophisticated bioreactor designs with unique performance characteristics will play a vital role in the economic manufacture of useful biotechnological products from natural and genetically modified cell systems of microbial, mammalian and plant origin[12]. Some of the advantages of bioreactors are Installation costs are low; Most bioreactors are constructed from common materials locally available such as lumber, fiberglass, and plastic pipe. They can be assembled using carpenters, plumbers, and earthmovers, depending on the amount of pretreatment the emissions require and operating costs on a low basis. These costs consists of electricity to operate the primary blower and the humidification pump, part-time labor to check on the process, and small quantities of macronutrients; Bioreactors have high DREs for certain compounds such as aldehydes, organic acids, nitrous oxide, sulfur dioxide, and hydrogen sulfide. Bioreactors are also designed to treat sewage and wastewater. The efficiency of these systems is the supply of free-flowing, chemically inert media that acts as a receptacle for the bacteria that breaks down the raw sewage. Some of these bioreactors often have separate, sequential tanks and a mechanical separator or cyclone to speed the division of water and bio solids[2]. Some of the disadvantages of these bioreactors are Large land requirement for traditional design, No continuous internal liquid flow to adjust bed pH or to add nutrients; Traditional design (shown in figure.2.) does not have a covered top, making it difficult to obtain representative samples of exhaust emission and to determine DREs, Natural bed media used in bioreactors must be replaced every 2 to 5 years. Bed replacement can take 2 to 6 weeks, depending on bed size. The main objective of this work was to study the different bioreactors and to compare the effectiveness of bioreactor in toluene degradation[13].

2. Different Types Of Bioreactors:

Assorted techniques have been used for treating toluene like physiochemical and biological treatment, especially bio filtration, bio degradation, thermal oxidation and catalytic oxidation. Among these the biological treatments convert toluene into carbon dioxide, water, salt and biomass that are eco-friendly and often thriftily viable. The aim of present study is to compare mostly used different bioreactor, operating parameters, packing materials and efficiency of bioreactors. Many bioreactors are used for VOCs degradation. They are as follows.

2.1. Jet loop reactor (JLR):

A jet loop reactor contains a central draft tube inside the reactor shown in figure.3. A bi fluid (liquid and gas) nozzle is located at the top or bottom of the reactor in a structure of two concentric cylinders. The gas delivered through one cylinder is dispersed by the liquid jet stream, delivered through the other cylinder. The liquid or gas can be circulated back to the reactor to increase the concentration of the gas species in the liquid phase. In JLR toluene is absorbed by circulating nonionic surfactants which is of polyoxyethylene based (LA5 and LA7) Polyol- based (Span 20, Tween 20 and Tween 81) and Surfactants. The toluene removal efficiency was 70% in Tween 81. The removal efficiency of toluene was not affected by Tween 81 which concentration is observed by effects of liquid flow rate[14]. Dissolving oxygen in the water is found to be superior to other reactors interms of oxygen transfer rate per unit power input[11].

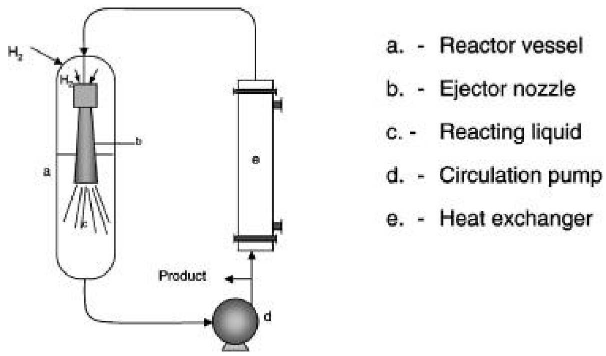

Figure.3. Schematic Diagram of Jet loop bioreactor[15].

2.2. Two Phase partitioning Bioreactor (TPPBs):

Two phase partitioning bioreactors (Shown in figure.4.) have been used in conjunction with an absorption column containing organic solvent to scrub benzene from an air stream. The organic solvent in the scrubber traps the benzene and is circulated to the TPPB, where benzene is transferred from the immiscible solvent to the cells in the aqueous phase[16] and the regenerated solvent is recirculated back to the absorber. The advantage of

TPPB system is toluene can be removed in a single stage system at high volatile organic compound loadings and high removal efficiencies[17].

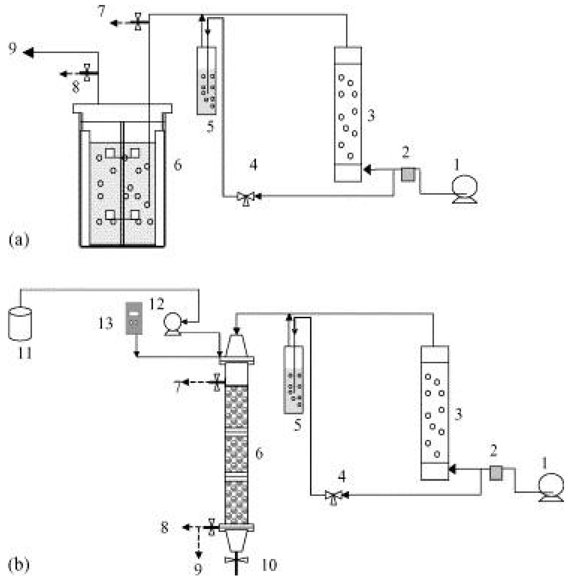

Figure.4. Schematic illustration of the stirred tank (a) and biofilter set up (b). (1) compressor, (2) mass flow meter, (3) humidifier, (4) precision valve, (5) hexane evaporator, (6) bioreactor, (7) inlet sampling port, (8) outlet sampling port, (9) outlet, (10) leachate purge, (11) nutrient solution, (12) peristaltic pump, (13) spraying system[18].

2.3. Fixed Film Bioreactor:

Fixed film bioreactors have become conventional technology for treating biodegradable contaminants in air and water shown in figure.5. Principle fixed film bioreactor applications include treatment of industrial waste waters, leachets or ground water and air emissions of volatile organic compounds. In the reactors, biological activity usually converts contaminants to innocuous end products such as carbondioxide, methane and water. Conventional fixed film reactor approaches involve aerobic, aerobic co metabolic (with aliphatic and aromatic organic inducers), and anaerobic metabolism. Emerging reactor approaches also include sequential anaerobic / aerobic metabolism[19].

Fixed bioreactors use either fixed, expanded or fluidized beds of inert or adsorptive media to support the biofilms biodegradation of contaminants. Practical inert media include plastic, stone, sand, wood and ceramic. Contaminants removal from the air or water is achieved through biofilm sorption. Adsorptive media, typically peat or granular activated carbon (GAC), remove contaminants from the air or water through both bio sorption and physical adsorption .While highly adsorptive media such as GSC or expensive, the high adsorptive capacity provide improved production to the biofilm by limiting microbial inhibition from toxic contaminants while increasing contaminant removal efficiencies , especially during treatment startup . GSC media also improve bio system response to widely varying contaminant concentrations[20] .

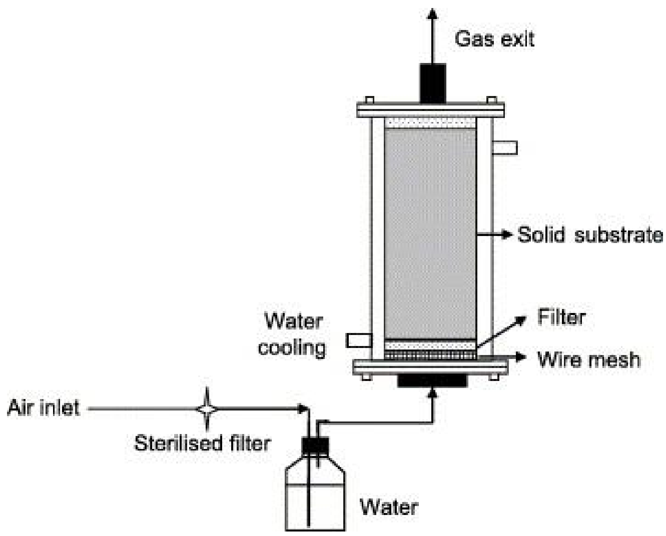

Figure.5. Schematic Diagram of Fixed film bioreactor[21].

The aerobic fluidized bed GAC filters are best suited for low to moderate concentration of contaminants such as typically found in ground water and leachates. These filters can treat aerobically degradable, poorly biosorbable, or Inhibitory contaminants in a slow way. Some contaminants will require the addition of appropriate co-metabolites for efficient biodegradation, where only aerobically degradable (metabolic and co-metabolic) and non-inhibitory contaminants are found in the aqueous stream, however, fixed film bioreactors with inert media may be used[22].

Anaerobic expanded or fluidized-bed GAC filters are best applied to moderate to high-strength aqueous waste streams such as leachates and industrial waste waters. In these waste streams, most contaminants are at least slowly anaerobically biodegradable. Highly halogenated contaminants and aromatic contaminants with multiple nitro groups (munitions) however are recalcitrant or require a co-metabolite for aerobic degradation. The presence of these compounds requires or favors anaerobic bio treatment. A significant advantage of anaerobic fixed film bioreactors is that oxygen does not have to be transferred to the aqueous stream, producing substantial operating cost savings, especially for high BOD streams. A major disadvantage is that slow anaerobic degradation rates for many compounds mean bigger reactors are required[23].

Aerobic fluidized-bed GAC bioreactors treating typical contaminant concentrations in ground water efficiently remove most contaminants. As an example, in a reactor with a 5-minute hydraulic residence time (HRT), concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX) were reduced[7] from 5,420 to 64 parts per billion (98.9 percent removal). Benzene removal exceeded 99.9 percent (less than 1 part per billion residual benzene). Anaerobic fluidized-bed GAC bioreactors[20] treating moderate- to high-strength leachate produced highly efficient removals (98 to 99 percent of chlorinated aliphatic VOCs, 85 to 97 percent of aromatic and ketone VOCs, and 97 to 99 percent removal of semivolatile organic compounds) at HRTs of 3 to 12 hours. The costs of these fixed film systems vary depending on the application characteristics. Capital costs are generally competitive with alternative technologies such as activated carbon adsorption, but operating costs, especially long term, are substantially lower than those of alternative technologies[24].

2.4. Fibrous Bed Bioreactor:

The bioreactor is made of a glass column with fibrous bed packed inside the fibrous bed (shown in figure.6.) was constructed by winding a porous wire cloth in a spiral configuration with 2-4mm gaps between each turn of the spiral layer. Ceramic saddles were placed at the bottom of the column to a depth of 2.5 cm to support fibrous bed and to ensure proper liquid distribution other reactor inlet the bioreactor system operated under well mixed condition with liquid recirculation at 40ml/min. The system was not aerated and was operated at ambient temperature. In fibrous bed bioreactor, Mineral salts medium (MSM) containing toluene is used as substrate with continuous feed which increases the cell density of co-culture Pseudomonas species and starts degrading toluene[25]. The ability of this reactor to continuously renew the cell populations and the adapt cells to the reactor environment. It does not depend upon the factors like pressure drop, Immobilization and loss of microbial activity over time[26].

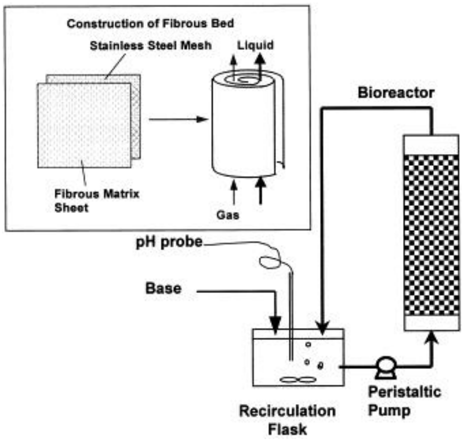

Figure.6. Schematic Diagram of Fibrous-bed bioreactor[27].

2.5. Bio Trickling Bioreactor:

Transparent plexiglass pipe with inner diameter of 10 cm was used to construct the BTFs. Each BTF column height was 65 cm and was equally divided in three sections shown in figure.7. A perforated plexiglass plate (Φ 10 cm) was positioned at the base of each section. This enabled the system to evenly distribute incoming gas steams and nutrient solution. A layer of sponge media of 10 cm high was packed on each plate. At the top of the BTFs, there is a 10 cm high headspace for nutrient feed and gas distribution. At the bottom of the BTFs, 10 cm high housing was also left to collect the leachate an discharge the effluent gas stream.Sample ports were placed in the plexiglass pipes between the bed sections for gas sampling and pressure drop monitoring. Both BTFs were operated in co-current mode with the gas and nutrient flow in downward movement. The gas stream, fed by an air compressor, was divided into two streams. One was delivered into a humidifier to be fully saturated, while the other passed through a flask containing liquid toluene reagent. Both airflow rates were regulated with two precalibrated flow meters respectively. Then the gas mixture was delivered to the top of the BTF and successively passed through three layers of sponge media. The contaminants in the waste stream were absorbed into and biodegraded by biofilms in the BTF. The purified gas stream exited out of the BTF through the outlet at the bottom of the BTF.A nutrient solution was periodically supplied to the BTFs, and was sprayed onto the media through a nozzle installed at the upper headspace. A microprocessor-based time controller was used to control a nutrient pump as needed. The liquid solution flowed downwards through the media and was discharged at the base of the BTF. Each BTF is equipped with an automatic water bath system surrounding the plexiglass pipe, with a water temperature of 25°C. These reactors achieve 99% of removal efficiency of VOCs[28].

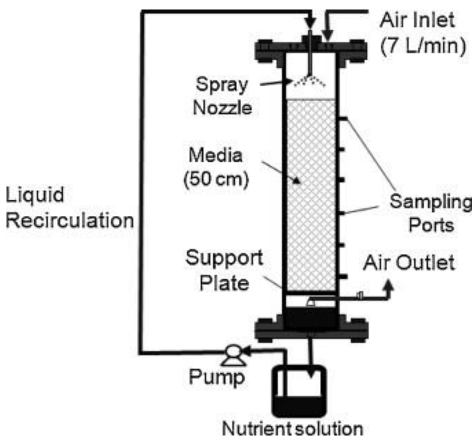

Figure.7. Schematic Diagram of Biotrickling filters[29].

2.6. Bio Scrubber Bio Reactor:

The bio scrubber attempts to solve two problems with the bio trickling bioreactor. 1. improve the absorption of pollutants into the liquid, and 2. lengthen the time the microbes have to consume the pollutants. These are accomplished in two ways: the tower packing is flooded with a liquid phase and the discharge effluent from the bio scrubber is collected in a storage tank (sump) before being recycled back to the bio scrubber. Flooding the bed increases the ability of the liquid phase to absorb pollutants because as the gas phase (emissions) impacts the bed media it forms tiny bubbles that greatly increases the surface-area of the interface between the gas and liquid phases. Increasing the interface-area improves the liquid phase's ability to absorb pollutants. The sump acts as reservoir for the liquid phase and permits additional reaction time for the microbes to consume pollutants. Reaction times can be increased to an hour or more, depending on the recirculation rate of the liquid phase and the size of the sump. This increases the time available for microbes to attach and destroy pollutants. This could save the cost of installing a humidification process. The bio scrubber has a smaller footprint than other bioreactors. This is an important consideration in congested facilities with limited available real estate. Because pH control and nutrient feed can be automated, it requires less attention than other bioreactors. Process is ideal for emissions that produce acids upon treatment. Bio scrubber can treat emissions containing particulate matter shown in figure.8[30].

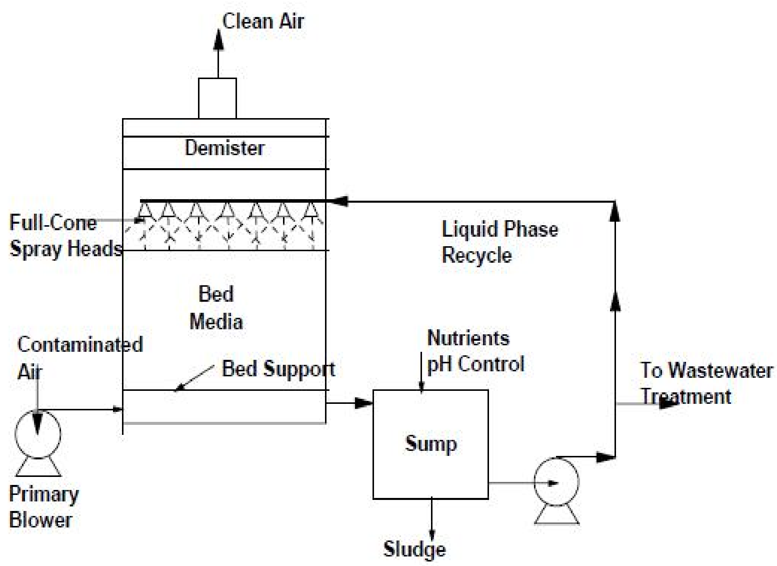

Figure. 8. Schematic Diagram of Bio scrubber bio reactor

2.7. Membrane bioreactor:

A membrane bioreactor (MBR) process for detoxifying industrial waste water process employed a silicone rubber membrane to extract the organic pollutant from the wastewater and deliver it to a bio medium where it is biodegraded shown in figure.9[31]. Because silicone rubber is an organophilic polymer, it does not allow the diffusion of inorganic species or water into the bio medium. As the organic pollutants diffuse through the membrane into the bio medium, the concentration gradient is maintained by the biological degradation of the pollutants. The MBR has been shown to be particularly useful when dealing with wastewaters which are saline, acidic/alkaline or which have inorganic compositions that otherwise preclude microbial function. It showed removals of VOCs 94.5% and 95% for the MBR and the CSTR, respectively. However, 34% of DCE removal in the CSTR was due to air stripping, while only a negligible amount (1.5%) was air stripped in the MBR showing the superior performance of the MBR process. Obtained >99% removal of toluene and dichloromethane using a laboratory-scale MBR. It is a compact process with high interfacial surface area between the air and biofilm phases, High cell densities in the biofilm can be achieved, Independent control of air and nutrient flow rates and control of biomass amount[32].

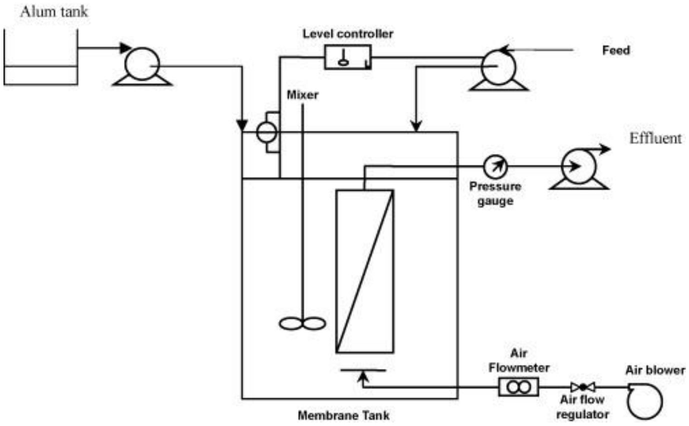

Figure.9. Schematic Diagram of Membrane bioreactor[33].

2.8. Fluidizedbed Bioreactor:

The uses microbial cultures immobilized on the surface of inert support materials, FBRS employ fluidized particles as a biofilm carrier for aerobic removal of organic compounds[34]. Sand or activated carbon has been the most frequently used biofilm carriers. In fluidized-bed reactors (shown in figure.10.) the biomass grows on granular support material. The main principle of this reactor type is the fluidization of the bed by high recirculation rates of the water to be treated. Recirculation of the water dilutes the concentration of the influent to a non-toxic level for bacteria and provides completely mixed conditions. Aeration of the groundwater is often designed to the recycle line. High biomass concentrations can be achieved in this process. Especially, fluidized-bed reactors with granular-activated carbon as support material have the advantage of establishing rapid microbial growth due to sorption of contaminants on the granular-activated carbon. In laboratory scale, fluidized-bed processes have been also used for anaerobic treatment[35]. The decomposition efficiency of various VOCs, including halogenated aliphatics, in groundwater using a pilot scale pure-oxygen aerated FBR[36]. Monitoring of bioreactor was easy in this type of reactor and good mixing was achieved. It achieved 99% degradation of Voltaile Organic compounds[37].

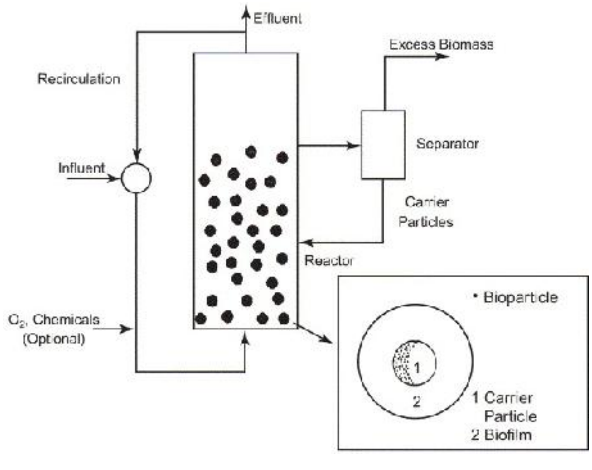

Figure.10. Schematic Diagram of Fluidized bed bioreactor[38].

2.9. Foam Emulsion Bioreactor (FEBR):

It consist of an emulsion of highly active pollutant degrading microorganisms and a water immiscible organic phase which is made into a foam with the air being treated[39]. The FEBR is similar to TPPB, but the amount of organic phase is low and it uses a biocompatible surfactant for foam production. To attain high volumetric pollutant removal rates, the FEBR relies on a high density culture of actively growing organisms. At the same time, bed clogging and associated pressure drop problems are avoided by using moving foam rather than an immobilized culture growing on a bed shown in figure.11[40]. It operates with a surfactant bubble solution containing pollutant degrading microorganisms. This type of bioreactor consist of an air compressor, an oxygen tank, activated carbon beds, dynamic system for generation of BTX vapors, foam column, cell reservoir, defoamer and controlling devices[41]. The compressed air after dehumidification and oil mist removing in the bed packed with ceramic enters to the activated carbon bed for elimination of VOCs and other organic pollutants. Then dry and clean air was mixed with pure oxygen. Fine foams were generated and rinse the column by passing a stream of air through emulsion. The sprayed and defoamed liquid returns to reservoir and is recycled to foam column. The mass transfer of BTX (Benzene, Tolune and Xylene) from the gas to the liquid phase was fast due to the increased interfacial surface area of the surfactant foams. In addition, the pollutants solublity was increased by increasing the organic phase concentration the optimum residence time (15s) of the bioreactor was less than biotrickling reactor. Low residence time increased the elimination capacity of bioreactor. Nominal and maximum elimination capacities for this bioreactor are higher than those of the biotrickling reactor, while the bed clogging and pressure drop where not encountered for this reactor[42].

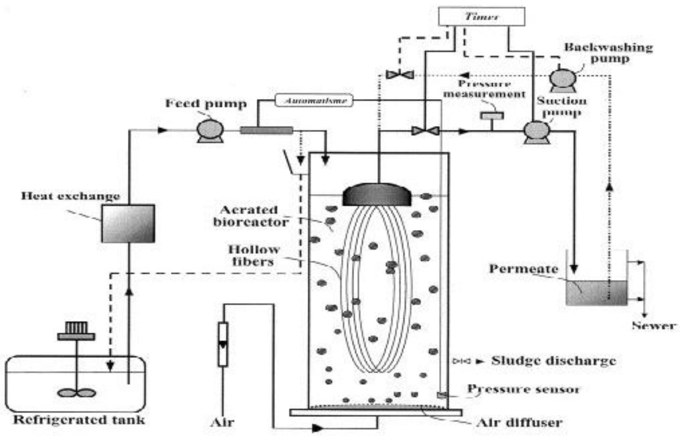

Figure. 11. Schematic Diagram of Foam emulsion bioreactor.

2.10. Up Flow Packed Bed Reactor:

This technology assures reasonable reactor volume and low hydraulic residence time, accompanied with high active biomass concentration in the reactor. The adhesion of microorganisms over solid support with large specific surface areas leads to high biomass concentration and high reaction rates since the bioreactor volume should be minimized[43]. In addition, on the surface of solid support, fixed film of anaerobic microorganisms are developed. As the organic pollutants passes by the active biofilm layer, penetrates into the biolayer and eventually biodegraded[44]. The Plexiglas is fabricated with an internal diameter of 6.2 cm and external diameter of 7 cm with the height of 100 cm. The total volume of the reactor was 3019 ml. The walnut shell was soaked in 1M NaOH solution for 24 h. The pre-treated walnut shell was washed with distilled water and packed into the column. The void volume of the packed bed reactor was 66%. A 1000 ml funnel shaped gas separator was used to liberate the generated biogas from the effluent and then the gas is led to the gas collector tank. The gas tank is a cylindrical glass pipe with an internal diameter of 80 mm and height of 1 m. The liberated gas is frequently measured for each HRT and the gas volume is recorded with respect to time. The gas tank is initially filled with water which was saturated with biogas. The volume of the liberated gas is demonstrated by the displacement of water in the gas tank. The UAPB reactor (shown in figure.12.) was operated at room temperature (25°C). The wastewater as a suitable substrate was continuously fed to the reactor using a peristaltic pump (SR25 adjustable flow rate, Thomas, Germany). The feed was introduced from the bottom of the column and uniformly distributed through the column using a perforated plate. The effluents were collected from the top of the column in a polyethylene container. Using this reactor removal efficiency was achieved 62% and COD removal efficiency for toluene is 80% [10].

Figure. 12. Schematic Diagram of Upflow bioreactor.

2.11. Comparative Study:

Each bioreactor has its own disadvantages. In a jet loop reactor only a limited amount of VOCs were treated, because the high concentration of VOCs causes bioreactor malfunction in the treatment of waste gases and Toluene degradation efficiency is low[14]. In TPPB the maximum toluene elimination capacity system is not reached and this system has some other disadvantages such as difficulty of scale-up, fixed diffusion rate and biofouling[17]. In Bioscrubber reactor is considerably more expensive to install than other bioreactors. It has a chemical scrubber at the heart of the process and resembles chemical-processing equipment more than other bioreactors. Over feeding can cause excessive biomass growth, which can plug the bioscrubber. Operating cost can be higher than other bioreactor processes. Need expensive and complex feeding and neutralizing systems. To control biomass growth, toxic and dangerous compounds must be inventoried and handled. Bioscrubber was not suitable for contaminants with low aqueous solubility[30]. Membrane Bioreactor associate with some of the disadvantages such as high cost, high cleaning process requirement and membrane fouling. Major limitation of using a membrane bio filter systems from the requirement that the contaminant has to dissolve in the aqueous phase and diffuse into biofilm because contaminants with low water solubility will follow low degradation rates where contaminants transport into the biofilm will limit the process efficiency[32]. In Foam bioreactor is associated with high cost and lower surface area for deposition of catalytic material and also this bioreactor is present in the initial stage of development[41]. In Bio trickling bio filter, proper selection of packing material would affect the performance of reactor in toluene removal and higher pressure drop across the bed also affect the toluene degradation[30]. In packed flow reactor, undesired thermal gradients may exist, Poor temperature control, channeling may occur and unit may be difficult to service and control[10]. In fluidized bed reactor mechanism are not well known, severe agitation can result in catalyst destruction and dust formation and results in uncertain scale up[45]. In Fibrous bed bioreactor is associated with some problems such as cost, membrane fouling and blockage[25]. In Fixed bed bioreactor has own enormous advantages compared to other bioreactors such as simplicity of operation, low cost, high reaction rate, enzymes or cell immobilized in appropriate carrier, which are packed in reactors resulting in high solid liquid specific interfacial contact area and the velocity of liquid creeping over the static solid particles substantially alleviates the film resistance to mass transfer and also high degrading efficiency of toluene using different micro-organisms[46].

Conclusion:

The present study briefly discusses about different bioreactors, its working principle and their performance in volatile organic compounds removal. Different bioreactors in VOCs removal have been already discussed. From the present study we conclude that Fixed film bioreactor has a sound knowledge and it is a well developed technology used to remove Volatile Organic Compounds, because of its long term stability of microbes with their packing material. Hence its high percentage removal efficiency (upto 99.1%) compared to other bioreactor.

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