BIO-OXIDATION TECHNOLOGY AS A MEASURE FOR AIR POLLUTION CONTROL

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Abstract:

Biological oxidation methods to counteract air pollution have been proven successful, economical and at the same time yield improved results. The air is contaminated by VOC's (volatile organic compounds) which heavily affects the pollution rate. Bio-filtration is a recently developed air pollution control technology that helps in eliminating gaseous VOC's by using a media filter material. Though filtration is really appropriate for physical separation, bio-oxidation implies biochemical destruction of VOCs through activities of micro-organism immobilized on a solid media. Biological controlling of gaseous VOCs have been found as simple techniques to control contaminated gases present in air due to its simple operating conditions, normal design and low cost. This review paper includes an overview of the VOC's affecting environment, the various bio-filters, analysis of the performance of the bio filters (working, design, efficiency etc) and also a comparative conclusive analysis has been done.

KEYWORDS: Voc's , Bio-filters, bio-oxidation

INTRODUCTION:

Bio oxidation is a natural biological treatment process (green process) used for biological control of air pollution. Combusting any fuel generates oxides of nitrogen (NOx), particulate matter, sulphur dioxide (SO_2), and carbon monoxide (CO). Bioreactors usually do not generate these pollutants or any hazardous pollutants. Products of a bio-reaction consuming hydrocarbons are water and carbon dioxide (CO_2).

The VOC emissions found from common sources are removed in this technique with the help of bacteria and fungi which absorb the emissions in bio-phases and help in curbing air pollution. Various VOCs released by industrial and manufacturing operations in to the air on a large scale are of significant environmental concern as some contribute to the ozone depletion potential, global warming potential, toxicity, and carcinogenicity. The major examples involve pesticides, building materials, markers and ink based solutions, paints, cleaning supplies etc. Bio-filtration units first came into operation around the 1980's in Europe where treatment of off-gases containing odours, low concentration volatile organic compounds and hazardous air pollutants (HAP's) were effectively treated with a cost effective and environment friendly approach as compared to combustion and adsorption methods. Although the use of open system bio filters was still much less practised as compared to traditional methods in that era but since the late 1990's bio-systems were built in major parts of the world that treated large volumes of filter material and compost media.

Principle of Bio-oxidation:

Microbes, fungi and bacteria, have relatively simple life cycles; they are present, eat, grow, reproduce and die. Some species of bacteria may have 100 generations in a 24- hour time period. As the mechanism based here for them involves aerobic respiration, it only helps in their functioning since their diet is majorly water, oxygen and carbon based compounds and some macronutrients including nitrogen and phosphorous. Bio-oxidizers use microbes to remove pollutants from air stream emissions through their metabolism of the compounds. The process typically involves drawing a contaminated air stream through some type of medium that hosts a community of microbes including either bacteria or fungi, or a combination of the two.

Bio-filtration units use microorganisms conceived on a porous media like peat, soil, compost or any mixture of these and thus are termed as microbial systems. A thin film of water to enrich nutrients surrounds the filter media and microbial culture and is known as biofilm. The VOC's which are composed in the waste gases entering the biologically active system are vented through it where the required soluble contaminants deviate into the biofilm and then get biodegraded with the resident microorganisms in the biofilm complete oxidation. Bio-filtration units comprise of several packed media and have been widely experimented using various types of media containing different kinds of impurities in them. The filters according to their principle are tested then for their efficiency with these media. However, the various media have both advantages and disadvantages. Soil enhances the process with its conventional use, can neutralize acids, and the microorganism content can be controlled. Soils also cannot be polluted or degraded by the filtration process because they don't consume gases or metabolic protects. Primarily organic gases are converted to carbon dioxide and water and the inorganic gases are converted to oxy calcium salts like $CaSO_4$ and $Ca(NO_3)_2$.

The technology has been successfully applied to a wide range of industrial and public sector sources for the abatement of odours, VOC's and air toxics, with an elimination efficiency of more than 90%.The process is environmentally and economically feasible and has low requirement of resources as well.

Characteristics for a bio-filter unit:

It requires the following evaluation criteria: process airflow, contaminants in the airstream, concentrations for each of the compounds, and temperature of airstream. Other factors include: site location, utility resources, and the ability to discharge a small amount of blowdown during a routine weekly maintenance program. Large land is required for a traditional design. Operating cost is high. An expensive, complex feeding and neutralizing systems is required. The process cannot work under unsteady inputs of the feed.

Types of bio-oxidation filters used in air pollution control:

- Convenional Bio-filters
- Bio-scrubbers
- Bio-trickling filters

Basic working:

Contaminated air streams are introduced into the system via induced-draft fans, the contaminants first encounter bacteria in an aerated sump and inorganic media with biofilm growth. Then in a compost media they are captured and digested by a community of naturally occurring microbes. The contaminants are utilized as a food source for the microbes and exhausted into the atmosphere as small amounts of carbon dioxide and water vapour. In this process, the microorganisms which are embedded to a porous medium are used to break down the degradable pollutants present in the liquid stream. The filter bed is of great significance as it holds the inert and biodegradable substances and it effectively ensures large surface attachment areas and extensive nutrient supply. The bio-filter performance characteristics are largely dependent on the properties and nature of the support medium that involves porosity, compactness nature, tendency to host more microbial mass and also water retention capability. There are although certain other relevant and critical filter properties which involve microbial inoculation, medium pH , temperature of system , moisture content and nutrition degree. The progress of filtration process, microorganisms (aerobic, anaerobic, facultative, bacteria, fungi, algae, and protozoa) are gradually developed on the surface of the filter media and form a biological film or slim layer known as biofilm. The crucial point for the successful operation of bio-filter is to control and maintain a healthy biomass on the surface of the filter

1) Conventional bio-filter:

Conventional bioreactors are a primitive technique of treatment of airborne contaminants, sewage and also some water borne waste. The bio-filter unit as shown in the figure is prominently a rectangular enclosure which consists of and enclosed plenum on the bottom frame, a filer media bed comprising the top of rack and a fan which recirculates the contaminated air stream.

Microbes or microorganism present ion nature are the only principal components used to treat the air stream containing malodorous compounds containing sulphur and phosphorous wastes and the voc's. The surface of the biofilter bed holds the microorganisms and they just require water and small quantities of present nutritional content. These microorganisms in turn use up or consume up these gaseous contaminants for energy purposes and in that process cleanse the air.

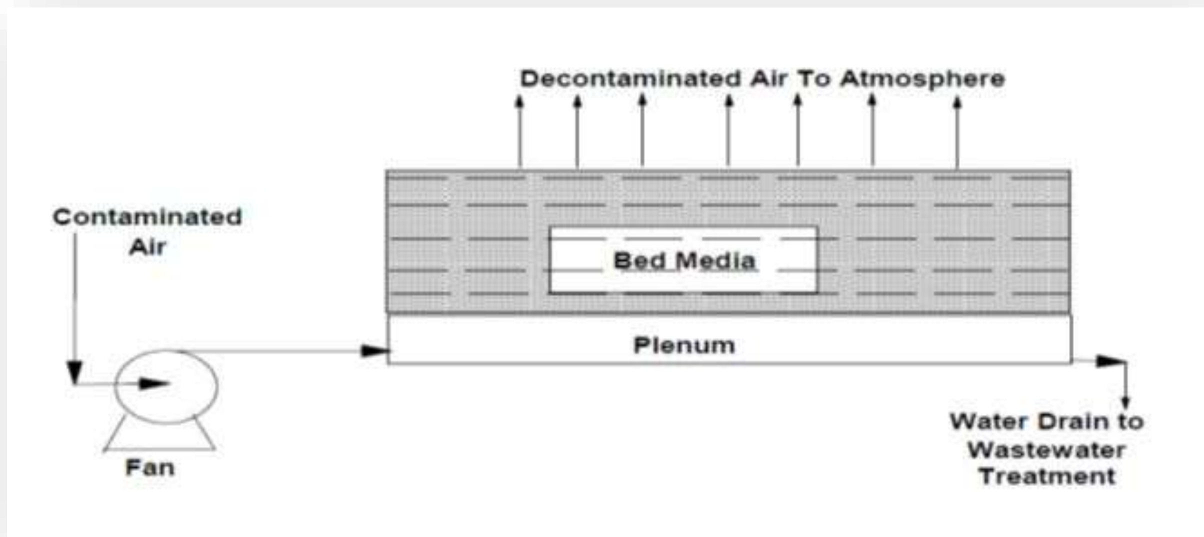

Fig 1: Conventional bio-filter unit[4]

The bio-filtration technique principally uses microbes or micro-organisms co-existing in nature and converged in the form of a biofilm that is used as a filtration membrane between the bed and pollutants on a porous medium such as compost, peat, synthetic substances, soil or their combination. This medium provides a hospitable environment in the form of moisture, temperature, oxygen, nutrients and pH to the microorganisms. When contaminated air stream passes through the filter-bed, contaminants are transferred to the biofilm which is developed on the packing materials. Pollutants are metabolized in their primary components (such as carbon dioxide and water in the case of carbonaceous pollutants) and additional biomass and innocuous metabolic products with the help of microorganisms. The contaminated air is passed through the porous media in the bio-filter unit and the core of the bio-filter is considered to be the packing media as it is the influencing factor in the pollutant removal performance and the total operational costs of filter.

In the past, bio-filters were commonly constructed as open single-bed systems. An enclosed system consists of a humidifier and a packed filter bed populated with microorganisms through which a waste airstream is passed. Influent air is pre humidified to maintain adequate moisture in the filter bed. Alternatively or in addition, water may be trickled over the bed. This water may contain nutrients required for the growth of microorganisms. Liquid trickling from the bottom of the filter bed may be bled off or recycled.

In bio-filters, as the contaminated air is passed through a bed of media, the contaminants and oxygen are first transferred to the biofilms formed on the surface of the media particles, and then metabolized by bacteria. In order to sustain microbial growth on the media particles, moisture is provided by saturating the process air before it enters the bio-filter unit. The moisture is also provided by intermittent, occasional spray irrigation of the media. The media within a bio-filter are normally composed of material such as peat, wood bark, soil, compost, coated ceramic particles, synthetically manufactured media, or a combination of these products. If properly designed, bio-filters can provide complete removal of the odour and VOC contaminants present in waste air.

Mechanism/Working of a conventional bio-filter:

The contaminants move from the air to the liquid phase or distributed media. The contaminants in the gas are either adsorbed onto the solid particles of the media or absorbed into the water layer which exists on the particles. As the contaminants move from several phases their concentration decreases as they reach towards the outlet. Wastes separate out between soil and gas, so that the VOC remain in soil longer than in air. The diffusion transfer happens through the water layer to the microorganism contained in the bed layer on the surface of porous media. Three chemical phenomenon that is, absorption, adsorption and diffusion work together in the bio transformation to remove contaminants from the air contaminated stream .The media of the filter functions in a dual nature for inorganic nutrients and as a supplement to the gas stream that is treated for organic nutrients. The absorbed gases are oxidized by the microorganisms to CO_2. The volatile inorganics are also absorbed and oxidized to form calcium salts. The oxidation of organic matter generates heat. A bio-filter primarily treats malodorous compounds and also water soluble pollutants and the voc's where it has the significant application. Industries employing the technology include food and animal products, off-gas from wastewater treatment facilities, pharmaceuticals etc.

The contaminant gases don't leave out any exit stream as the fan recirculates the air stream into the unit and it keeps on the process of pollutant removal and also the plenum holdup increases as the packing media gets more and more off stream contaminants.

Bio-scrubber:

Bio-scrubber unit consist of two subunits namely an absorption unit and a bioreactor unit. Input gaseous contaminants can be transfer to the liquid phase with the help of absorption unit. Column may contain the packing material and gas as well as liquid phases flow counter currently, however in liquid phase further treatment is also required. Packing medium used in bio-scrubber, is used to provide increased transfer surface between the VOC and the aqueous phase .After the gaseous treatment, solution of the waste may be recycled back. In the biological reactor, the pollutants that have been absorbed by the wash water are biologically degraded. Then purified liquid is circulated to the scrubber to reabsorb pollutants.

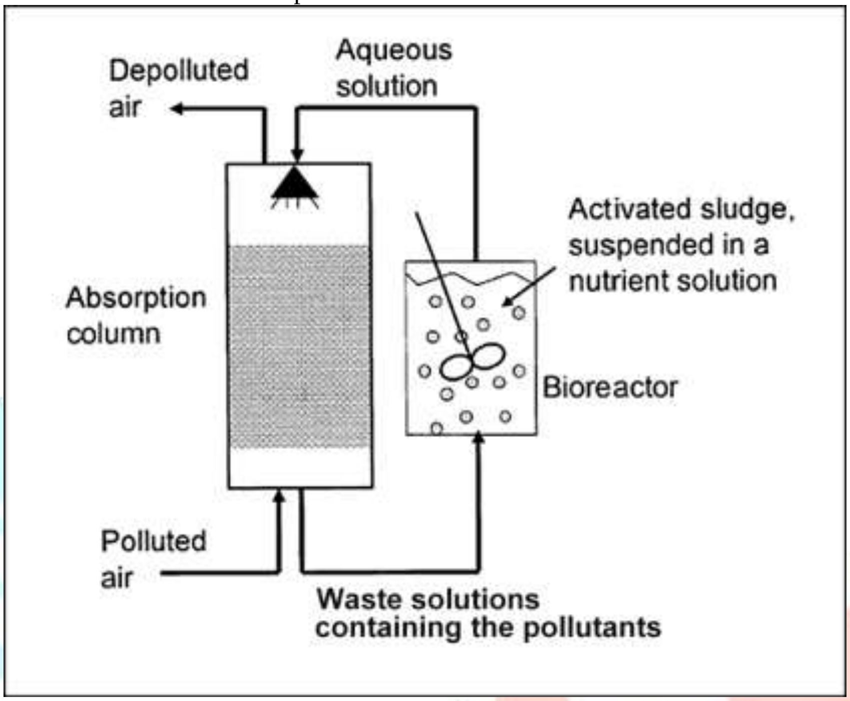

Fig 2: A bio-scrubber unit containing one adsorption column and a bioreactor [6]

Bio-scrubbers are mostly used where the biological degradation products (such as the acids produced during H_2S and NH_3 removal) may harm the bio-filter bed.

Mechanism of a bio scrubber:

In bioscrubbers, the pollutant in the gas phase is removed by absorption in the re-circulation liquid in a gas–liquid contactor. Subsequently, this pollutant-laden liquid is regenerated by the microorganisms suspended in the liquid in a bioreactor with supplementary oxygen, to be returned to the contactor . Nutrient addition and pH are continually controlled to maintain microbial growth and high activity. The excess biomass and byproducts are continually purged from the system. The gas–liquid contactors are designed to favor mass transfer from the air to the liquid phase, thus reducing equipment volume.The contactors can be packed towers, venture scrubbers, spray towers, etc. In the bioreactor, the liquid is regenerated by the suspended microorganisms, and CO_2, H_2O and other mineral products are produced.Most of the reactors are vessels where air is bubbled, and resemble activated sludge tanks.

The biologically degradable hydrocarbons are converted into H_2O and CO_2 in the bio-scrubber. The hydrocarbons that cannot be degraded are left in the system with the wash water unit. Components such as H_2S and NH_3 are converted into sulphate and nitrate respectively. Regular draining needs to take place in order to keep down the salt content and the level of non-degradable hydrocarbons.

Bio-scrubber is a modified water scrubber. The significance of this filter is its adaptability to several kinds of contaminant streams, be it aqueous, solid or wastewater. The microbes are pumped into the bed via the spray thus resulting in increase of solubility of the contaminants and ensuring effective removal, much better than that could be done with only water. The sludge stream then is diverged into a water treatment system where it biodegrades the dissolved VOC's and generate a new sludge for usage. This technique thus is best touted for streams with backpressure characteristics and also for heavy or large flows. The only concerning factor is need of an additional treatment system to biodegrade the voc's and pollutants rather than stripping off those wastes from the water and generating a damp but non odorous sludge. Basically, the bio-scrubbing is effective to deal with toxic and odorous gases as well as wastewater contaminants. There are various methods available for scrubbing of waste and contaminated effluents but those component systems haven't yet been scaled or their performances at waste disposal points and removal tendencies has been determined.

Bio-trickling filters:

Among the various biological oxidation techniques, bio-trickling filter (BTFs) are the most preferred technique due to their stable operation, high removal rates, low capital expenditure as well as better pH control. However, they are prone to excess biomass accumulation in the bed.

Design or construction of a trickling filter:

A trickling filter is a wastewater treatment process that is usually a round, vertical tank that contains a support rack and is filled with aggregate, ceramic or plastic media to a height of 3 to 15 feet. A vertical pipe is installed in the middle of the unit which consists of a rotary connection on the top portion. Along with it a spray arm is attached to the same rotary connection which composes nozzles installed all over its length for optimum contaminant passage. Now here the purpose is to ensure the wide rotation of the spray arm around the top of filter to ensure maximum effluent entry and transfer and thus the nozzles are located slightly off centre to provide necessary force for the rotation of spraying arm at the top point. Another recirculating pump is used in the filter to pump the liquid from wastewater reservoir located at the bottom into the spray arm. Liquid level in the sump is maintained with an automatic effluent make-up system. A biofilm forms on the packing surface. This is a highly active component that ensures the pollutant removal from the effluents and then the microorganisms effectively decompose the effluent matter.

A bio-trickling filter is a combination of a bio-filter and a bio-scrubber. The bacteria responsible for decomposition are immobilized on a carrier or filter material. The filter material consists of synthetic foam, lava or a structured plastic packing. The surface of the unit holding the filter bed has to be effective in terms of allowing the bioorganic material to adhere to it extensively. Packing materials are made of chemically inert materials, such as plastic rings. Nutrients are not available in these materials.

Working Principle: The waste air is in fact treated by combination of accumulation (adsorption) on dryer zones and dissolution (absorption) in humid areas of the biofilm. Having entered the cells of the microorganisms contained in this film, the dissolved pollutants are biologically decomposed. The biofilm, growing on the packing material of the trickling bed, is kept humid by means of irrigation (trickling). Apart from its function to provide the biofilm with humidity and minerals, the irrigation liquid can also be used to neutralize pH relevant waste air compounds and decomposition products. Thus it is possible to use bio-trickling filters for the treatment of waste air containing high concentrations of H_2S and NH_3.

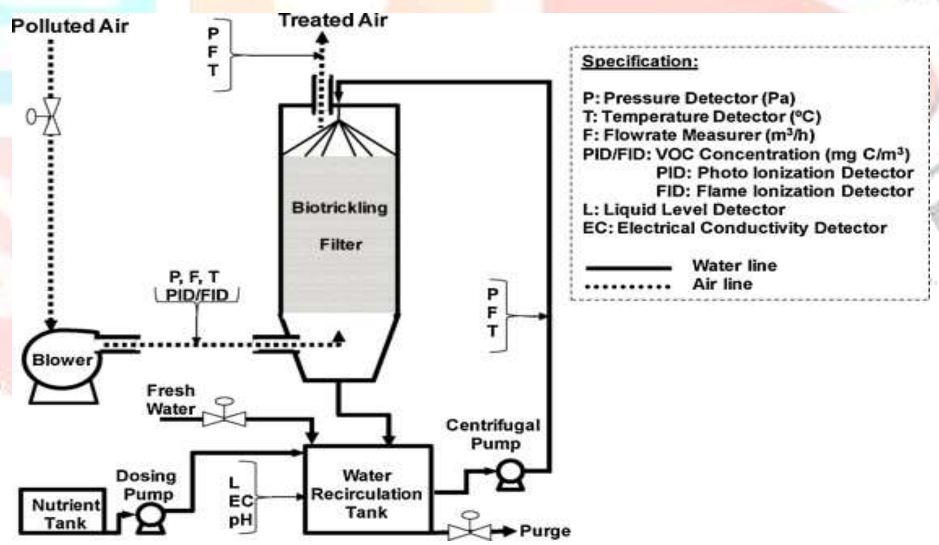

Fig 3: a bio-trickling filter unit [11]

Conventional trickling reactors are essentially similar to the bio-trickling filter although the recycle ratio and efficiency as well as the liquid hold up in the BTF have been significantly improvised. And as per usual trickling phase properties, pollutants are contained into the air phase which are the emissions to be treated and those have to be dissolved in the aqueous phase for the consumption by microorganisms. The emissions once they enter into the air phase they travel through the packing or surface packed bed and are absorbed from the air phase into the liquid phase so that it ensures maximum level of contact with the available biomass. In conventional trickling filters the contaminants or pollutants that enter into the system are already dissolved into the effluent phase. Water is added to the reservoir to make-up for water that has evaporated. Accumulated bio-sludge is periodically removed from the reservoir.

Mechanism and operation of a Bio trickling filter:

In bio-trickling filters, contaminated air is forced through a packed bed, either downflow or upflow. The packed bed is generally made of an inert material such as a random dump or a structured plastic packing, or less often, an open pore of synthetic foam or lava rocks. The structured packing helps in maintain the attachment of biofilm to the surface bed and thus provides adequate gas-liquid contact,. An aqueous phase is passed over the packing during the operation. The liquid phase is essential as it generates moisture, mineral content of the microbial mass and process culture and also helps in maintaining the pH level of system, The system is continuously supplied with essential mineral nutrients such as nitrogen, phosphorus, potassium, and trace elements via a liquid feed.

Bio-trickling filters work because of the action of the pollutant degrading microorganisms. The removal of malodorous vapours subjected to the surface bed once the micro-organisms degrade them is done with the help of primary degraders which are aerobic microbes which consume the pollutant as a means for carbon and energy. On the other hand autotrophs are used as primary degraders for inorganic gases or vapour removal namely hydrogen sulphide or ammonia which aren't in huge quantities yet need to be treated and these autotrophs use these pollutants as a source of energy and carbon dioxide for growth purposes.. The removal of compounds such as dimethyl sulphide or dimethyl disulphide will require both autotrophs and heterotrophs to be present. In any case, the bio-trickling filter will host a wide variety of microorganisms, similar to those encountered in waste water treatment operations. The microorganisms responsible for pollutant removal in bio-trickling filters are usually aerobic because bio-trickling filters are well aerated systems.

Media used in bio trickle filter:

Bio trickling filters are made from inert materials to ensure the best treatment of media in the filters. The prime transfer here occurs as the contact between microbes and the contaminants which tends to diffuse through the liquid film once the contaminants are diffused through it; this leads to development of two most critical parameters for the operation which are the liquid flow rate and its recycling rate through the bio-trickling filter. Factors influencing filter volume and removal tendency are the kinds of material used and the surface area they will consume. Along with it there are several characteristic factors to be maintained in order to maintain effective functioning which include type of media, weight, durability, cost per area and not volume and also the availability of the material. A proper balance between effective cost and filter volume impacts the design of filter. It must be noted that media which is too small will tend to trap particles and clog from bacterial film growth. On the other hand, the material needs to have high strength to support the media bed above it and should ensure proper hold up tendency and should not break down under normal operating conditions as well as the post operation cleansing conditions.

Parameters that need to be maintained for efficient working of the biofilter:

1) Moisture Content:
   - Microorganisms need a moist environment.
   - If there is a larger air flow, the media shows a tendency to dry out.
   - Optimum level is about 20-60%.
2) Temperature:
   - 30-40 degrees is the most optimum temperature range for the microorganisms.
3) Oxygen Level:
   - Most of degradations are aerobic.
   - The microorganisms use the oxygen present in the compost or induces media and not directly from the atmosphere.

4) Nutrient Supply:
   - For aerobic microorganisms, the O/N/P ratio is estimated as 100/5/1.
   - They compose mainly of nitrogen, phosphorous and other trace metals.

Table 1: Classification of bioreactors for waste gas purification [13]

Reactor type	Microorganisms	Water phase
Biofilter	Fixed	Stationary
Biotrickling filter	Fixed	Flowing
Bioscrubber	Suspended	Flowing

Comparative analysis and conclusion:

On evaluation of performance statistics of all the mentioned bio reactors, the bio-trickle filters offer best performance and efficiency of about 80%. Bio trickle filters offer more in terms of almost every aspect except for cost efficiency. It offers better portability, better conditions in extreme weather, more suitability, compact nature and offers more choices of media as well as recycles compost for greater removal of toxic gases as well as wastewater.

Biofilter systems plays very important role in control of air pollution. Biofilter is successful only when microbial ecosystem is healthy & vigorous. The design of the biofilter system needs a proper understanding of the site for the process, conditions required, limitations of the site, components of the biofilter, and also the economical aspect of the system.

Emission conditions: It depends on the whether the emissions are acidic or basic which then must be neutralized before entering a bioreactor. That is done to ensure a pertaining humidity level and if it isn't anywhere close to 100 percent, they need to be humidified before entering a biofilter. If the emission stream is too hot or too cold, it must be cooled or heated. Emission streams which compose of dirt or polluted particulate matter, it should be cleaned before entering into the biofilter. Suspended particulate matter doesn't need any cleaning though. Highly concentrated or toxic emissions are not favourable for a biofilter reaction.

In short, the biofilters are having emerging applications for the treatment of heavy metals, contaminated waste. It has to be ensured that before operating a biofilter, the operating parameters and the ideal conditions for the microorganisms need to be maintained which will in turn provide higher removal tendency and efficiency. The major advantages like the simple construction, optimal environment needs, higher hours of contaminant removal and continuous VOC removal efficiency result in a very economical usage and effective treatment technique.

Future suggestions:

With the added emphasis on greenhouse gas emission reductions, and the cost and supply issues with natural gas and fuel gas , it seems bio-oxidation systems are destined to play a major role in the abatement of air emission control in the future.
Replacing a conventional RTO with bio-oxidation system will significantly reduce greenhouse gas emissions by 5000-6000 tons per year and also save thousands of cubic feet of natural gas which can be made available to the families and households.

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