<u>บทความวิชาการ</u>

การกำจัดสารประกอบ VOC ที่ปนเปื้อนอยู่ในอากาศ โดยกระบวนการไบโอฟิวเตรชั่น

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บทคัดย่อ

บทความทางวิชาการที่ได้รวบรวมขึ้นมานี้มีวัตถุประสงค์เพื่อต้องการที่จะแนะนำความรู้ทางด้าน biofiltration ให้แก่ผู้อ่านทั่วๆ ไปได้ทราบ ซึ่ง biofiltration เป็นเทคนิคหนึ่งที่ใช้ในการกำจัดมลพิษทางด้านกลิ่นหรือสารเคมีที่ระเหยง่าย (volatile organic compound, VOC) ที่ปนเปื้อนอยู่ในอากาศ มลพิษทางอากาศดังกล่าวเกิดขึ้นในระหว่างขบวนการผลิตในโรงงานอุตสาหกรรมเช่น โรงงานผลิตสี โรงงานชุบเคลือบโลหะ โรงงานผลิตสารเคมีที่ใช้เป็นตัวทำละลาย (เช่น เบนซีน โทลูอีน) เป็นต้น หากอากาศที่ปนเปื้อนมลพิษจากโรงงานอุตสาหกรรมไม่ได้รับการบำบัดก่อนปล่อยออกสู่บรรยากาศก็จะก่อให้เกิดปัญหามลพิษต่อสิ่งแวดล้อมและส่งผลกระทบต่อสิ่งมีชีวิตอื่นๆ รวมทั้งมนุษย์ด้วย

วิธีการของ biofiltration จึงเป็นอีกทางเลือกหนึ่งที่น่าสนใจและชวนติดตามสำหรับงานทางด้านการบำบัดมลพิษของสารประกอบพวก VOCs ในอากาศเสีย วิธีการของ biofiltration ในการบำบัด VOC อาศัยหลักการการบำบัดของเสียโดยใช้ microorganism เป็นตัวกำจัดของเสีย (ซึ่งจัดเป็นวิธีการทางชีวภาพบำบัด) ผสมผสานกับการบำบัดของเสียทางกายภาพด้วยวิธีการดูดซับ (adsorption) ไปพร้อมๆ กัน จึงทำให้ประสิทธิภาพในการบำบัดมลพิษในก๊าซเสียดังกล่าวค่อนข้างสูง นอกจากนี้แล้วต้นทุนในการดำเนินการค่อนข้างต่ำ ดังนั้น เทคนิค biofiltration จึงเป็นเทคนิคน่าสนใจโดยเฉพาะในสภาวะที่กฎหมายทางด้านมลพิษอากาศ (air pollution) ที่ค่อนข้างจะเคร่งครัดขึ้นทุกวัน

The Removal of VOC from Off-gas by Biofiltration Process

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Abstract

The objective of this article is to introduce a biofiltration technique, for off-gas treatment, to the readers. Biofiltration is a process which utilizes to remove odor or volatile organic compound (VOC) in wasted-gas. This process is basically removal the VOCs or organic gases by oxidation of these substances from contaminated air by beds of compost or soil, where in microorganism oxidize organic compound to CO_2 and H_2O which are harmless to the environment. In addition, the operation and maintenance cost of biofiltration process is much cheapper comparing to the other existing method of air toxic treatment. Recently air emission of VOCs are subject of increasingly stringent environmental regulations, to comply with the stricter air pollution regulation, VOCs contaminated airstream must be treated to reach an acceptable level before releasing to the atmosphere. Therefore biofiltration technique is a promising option for VOC treatment in this decade.

Introduction

Air emission of volatile organic compounds (VOCs), including solvent vapors, are the subject of increasingly stringent environmental regulations. Volatile organic compounds usually known as hydrocart ons pose a potential health risk directly from chemicals such as benzene and indirectly through production of "smog" in large industrialized cities. The "smog" is formed in the atmosphere as a result of reactions between certain organic compounds such as hydrocarbons and nitrogen oxides. These two types of substances are the "precursors" to the components of photochemical smog. The main effects of photochemical smog pollutants are eye irritation, respiratory diseases, vegetable damage, reduced visibility and various effects on materials.

The major VOC emission sources are grouped into six categories : motor vehicles, solvent evaporation, oil industry, incineration, manufacture of chemicals and combustion at stationary sources. About 114 volatile organic compounds including benzene, toluene, and dichloroethane are listed as priority pollutants by EPA. These air emission pollutants must be treated by either conventional or non-conventional techniques in order to comply with the regulation of discharges. Among emission control techniques such as condensation, flaring, catalytic oxidation, or activated carbon adsorption, biofiltration (biological technique) appears to be a cost-effective and environmentally sound approach.

Biofiltration is a relatively new technology for air pollution control. It employs microorganisms which have the ability to biodegrade volatile substances present in airstream. Such microorganisms are immobilized on porous solid support particles and form biolayers on the surface of the solids. The particles are placed in open or closed structures (reactors), in a packed - bed configuration. The contaminated airstreams are passed through the reactors , which are known as biofilters , and the pollutants are transferred to the biolayer where they undergo biological destruction to CO_2, water, and neutral salts[1]. Figure 1 shows a schematic of a single bed filter. Proper selection of the microbial culture and of the biofilter size results in a pollutant-free airstream exiting the reactor.

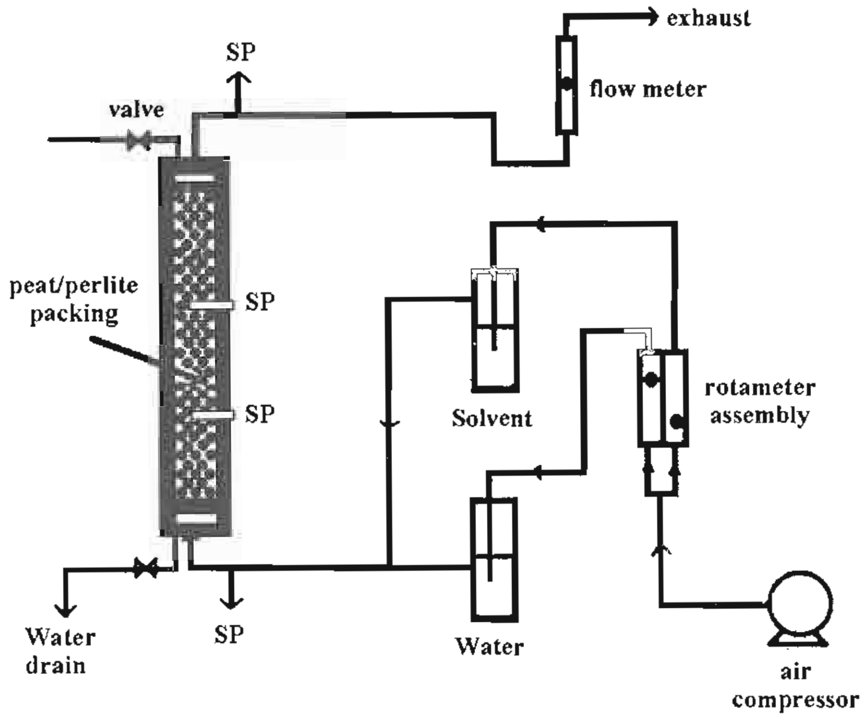

Figure 1. Schematic of the biofilter unit, SP standards for sampling port (at the inlet, outlet, and point along the length of the bed)[2].

When compared to other existing air pollution control technologies, such as flaring, catalytic oxidation, incineration, and activated carbon adsorption, biofiltration is much more economically efficient as it leads to the destruction of pollutants at ambient temperature, and the formation of innocuous final products. Biofiltration is well suited for applications involving high volume/low concentration of VOCs. It also requires low materials costs and minimal maintenance. Only recently the biofilters have received attention for volatile organic compounds (VOCs) and air toxic treatment [3]. In the U.S.A., an intense interest in biofiltration seems to have been catalyzed by the Clean Air Act Amendments (CAAA) of 1990[2], which require stricter regulation for air emission, as well as economic viability of this technique.

There are various kinds of adsorbent media that have been used in conventional biofiltration. These adsorbent media are soil, peat, compost, and wood bark chips. Today, state environmental and regulatory agencies are imposing tighter VOC emission limits in air /vapor emission streams. Thus, activated carbon has received increased attention as an adsorbent medium for

VOCs and air toxics removal in biofiltration, because it offers a solution to meet the stringent air quality standards[4].

The concept of using microorganisms for the removal of environmentally undesirable compounds by biodegradation has been well established in the area of wastewater treatment for several decades. In Europe, biofiltration has been used successfully to control odors, and both organic and inorganic air pollutants that are toxic to humans as well as VOC from a variety of industrial and public sector sources. In the United States, the control of air contaminants by biological processes has not been widely applied. Not until recently, however, have biological technologies been seriously considered in the U.S. for the removal of pollutants from other environmental media. Biofiltration is likely to find more widespread application in the U.S. in the near future[5]. In addition to a few existing installations, several full-scale projects are currently in the planning stage or under construction[5]. To date, most biofilters have been built as open single bed systems. The biofilters originally built in the U.S. were mostly soil bed for which biologically active mineral soils were used as filter materials. Due to the low biodegradation capacity of soil alternative, support media need to be investigated.

Biofiltration is a very complex process. It involves mass transfer and reaction and is also affected by the characteristics of the flow of the airstream through the reactor. The removal and oxidation rates depend on the biodegradability and reactivity of the gases. The VOCs can be classified according to their biodegradability. They are (i) rapidly degradable VOCs like alcohols, aldehydes, ketones, ethers, esters, etc. (ii) slow degradable VOCs like hydrocarbons, phenols and methylene chloride. (iii) very slowly degradable VOCs like halogenated hydrocarbons, polyaromatic hydrocarbons, etc. Since biofilter efficiency is dependent on many factors including degradation capacity of filter material, contaminant loading rate and pollutant detention time. Design parameters such as moisture content, pH , temperature, microbial activity, particle size and density etc. must be investigated to optimize biofilter performance. These affecting factors are discussed briefly in the following section.

Filter Material

One of the key components of the biofilter is the microorganism support medium. In order for a biofilter to operate efficiently, the filter material must meet several requirements. First, it must provide optimum environmental conditions for the resident microbial population in order to achieve and maintain high degradation rates. Second, filter particle size distribution and structure should provide large reactive surface and low pressure drops. Third, compaction should be kept to a minimum, reducing the need for maintenance and replacement of the filter material. It should be as inexpensive as possible.

Since it provides favorable conditions for microorganism, compost, peat, soil, bark, tree trimmings are widely used as a conventional filter material. Most loam soils worked well for odor control while clays performed poorly. However, soils are limited in effectiveness because they are prone to clogging.

Compost has been more widely used than soils[6]. Compost is inexpensive and works well for removing pollutants. It contains an abundant and diverse population of microorganisms. Its loose structure of large particles results in good air flow characteristics. Compost does suffer from aging effects, resulting from microorganisms metabolizing the compost. As a result, compost beds settle over time, creating short circuiting. Consequently, compost beds must be replaced every few years[7].

Recently, research works have been studied on the use of pelletized and ceramic structured media in biofilter[8, 9] in order to improve gas distribution, pH and the capacity for removal of excess biomass from the media. Other materials , such as porous clay or polystyrene spheres, are sometimes added to increase reactive surface and durability, reduce back pressure and extend the filter material's useful life[5].

Another optional material with promise is granular activated carbon (GAC). Granular activated carbon has many characteristics which suggest that it could be a good biofilter material[7]. It is highly adsorptive, and thus may offer advantages in the physicochemical removal of contaminants. Shock loads can be removed by adsorption, then biologically degraded. It was reported by other authors[10, 11] that using the GAC bed column as the support medium provided performance superior to those using soil and diatomaceous earth. Activated carbon can be used to increase the filter's buffer capacity for emissions from sources that operate only intermittently and can reduce the required filter volume significantly[5, 12].

Adsorption treatment using granular activated carbon (GAC) is effective for a wide range of contaminants and concentrations, and can be sized to any treatment efficiency desired. However, once the adsorptive capacity of the carbon is reached, it must either be regenerated or discarded. Carbon replacement costs can be substantial.

Microorganism

There are several groups of microorganisms that are known to be involved in the biodegradation of contaminated air in biofilters, such microorganisms are bacteria, actinomycete, and fungi. Compost-based filter material typically shows significantly higher population densities of these organisms than soil and peat[5]. Growth and metabolic activity of microorganisms in a filter depend primarily on the presence of dissolved oxygen in the biofilm, the absence of compounds that are toxic to microorganisms, the availability of nutrients, sufficient moisture, and suitable ranges of temperature and pH. Thus the control of these parameters, is essential for obtaining the optimal conditions to operate a biofilter system.

Biofiltration relies predominantly on heterotrophic organisms that use organic off-gas constituents as carbon and energy sources and convert them to CO_2. Bacteria such as Pseudomonas and Nocardia degrade small organic molecules that are easily ingested into their cells. Some species such as Flavobacterium can adapt to oxidize such compounds as pentachlorophenol. Soil and compost contain approximately one billion bacteria per gram. Fungi tend to degrade more complicated molecules. The fungi population is about 100,000 per gram of soil or compost[13]. Microbial cultures have been developed in the laboratory in order to obtain better microbial cultures for degradation specific compounds. In addition, the proper selection of microbial cultures to degrade specific compound is one of factors that effects the removal efficiency of biofilter.

Raw – Gas

Since biofilters can be poisoned by the presence of off-gas constituents that are toxic to microorganisms because of their chemical nature (e.g. SO_2) and/or by excessive concentration, a characterization of type and quantity of all off-gas constituents should always be conducted prior to the design of a filter. In many cases, the elimination of a substance of which is toxic to microorganisms from the emitting process, or a change in the ventilation systems, can make the off-gas suitable for biofiltration. High particulate loads in the raw gas can adversely affect the operation of a filter in several ways. Clogging of the air distribution system and the filter material itself by grease and resins can occur. The deposits of dust in the humidifier will generate sludge and can result in improper humidification. In such cases the installation of a particulate filter is required[5]. Temperature of biofilter bed influence the microbial activity as well. The bed temperature is primarily determined by the input gas temperature, since the heat evolved by VOC oxidation is negligible. It is recommended that , for optimum results, off-gas temperatures be maintained between 20° and $40^{\circ}C$[5]. Hotter off-gas will require cooling while low temperature off-gas need preheating before feeding off-gas to the biofilter[5, 13]. In addition, raw gas other than VOCs wasted gas can also be treated by biofiltration process. Methanol, which was listed as one of the hazardous air pollutants under the CAAA of 1990, has received attention to be treated by biofiltration process. Krailas et al.[14] utilized compost as a filter medium to eliminate high methanol loading in biofiltration process. The detail of this study can be found in research work of Krailas et al.[14].

Moisture Control and pH

Maintaining an optimum moisture content in the filter material is the major operational requirement for a biofilter. Without providing additional moisture, raw gas would quickly dry out the filter bed. Moisture is essential for the survival and metabolism of the resident microorganisms and contributes to the filter' s buffer capacity[13]. Insufficient moisture content can also result in compaction, breakthroughs of incompletely treated raw gas and the formation of anaerobic zones which emit odorous compounds. A moisture content between 40-60% by weight is considered optimal[5]. In most biofilter installations the raw gas is humidified in a spray humidifier. A degree of saturation of more than 95% is desirable. Excess drainage from the filter bed is the only potential source of waste water discharge from a biofilter. In cases where acidic degradation products are formed, the drainage will also be characterized by a low pH. In order to prevent the build up of solids in the humidifier, periodic discharge of some drainage is usually required.

Since most microorganisms prefer a specific pH range, changes in the pH of the filter material will strongly affect their activity. The pH in compost filters is typically between 7 and 8, a range preferred by bacteria and actinomycete. In some cases the biodegradation of air pollutants can generate acidic by-products resulting in pH dropped. This can destroy the resident population, if not eliminate, the filter 's degradation capacity can be reduced. In such cases chemical buffers, such as lime, are added.

Biofilter Removal Efficiency

Removal efficiency is the fraction of input pollutant removed. The steady state removal efficiency of VOCs by biofiltration is approximately first-order with respect to VOC concentration and is rather constant over a wide range of concentrations[13]. The reaction also depends on the oxygen concentration, microbial population, and microbial nutrient supply, but these are usually in excess of what is required to oxidize the VOC input[15]. For the range of VOC 0-500 ppm the removal efficiency of the biofiltration is approximately as the following (Bohn, 1992) :

$$\text{Removal efficiency} = \left(1-\frac{c_1}{c_2}\right) = 1-e^{-kt}$$

where c_1 and c_2 are input and output VOC concentration respectively, k is an empirical reaction rate constant, and t is the residence time of the carrier air in the bed. Constant k varies with temperature and a function of the VOC's biodegradability[13].

To achieve a given removal efficiency, the primary design parameter is the air residence time in the bed. The residence time of the carrier air for 90% removal of aldehydes may range from 30 seconds to a few minutes. For 90% removal of trichloroethylene, the air residence time may be as much as 150 minutes[13].

Conclusion

Up to this point, it can be seen that biofiltration is a promising technique to treat VOCs wasted gas resulting in a pollutant-free airstream. The removal of VOCs contaminant by biofilter is due to both physical adsorption and biodegradation therefore the high removal efficiency is a result. However, to obtain a high removal efficiency various parameters such as influent concentration, filter particle size and pH media which influence the performance of the biofilter must be considered. Further more, biofiltration offers significant advantages over other air treatment technologies such as low initial cost, minimal maintenance requirements and absence of secondary pollution. Due to these significant advantages of biofitration plus an increasing in stingent air pollution regulation, the attention on biofiltration has been increased recently for air pollution control.

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