REMOVAL OF VOC FROM WASTE GASES BY BIOFILTRATION TECHNOLOGY

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Abstract. *This paper presents some results and experiences obtained from operation of bench and pilot-scale biofilters, desirable for odour and volatile organic compounds (VOCs) removal from waste gases. Recently, biofiltration competes with all the technologies that can be found in industry such as incineration, adsorption, catalytic oxidation and scrubbers. Biofiltration offers an often cost-effective and environmentally benign alternative technology that utilizes microbial activity for the aerobic degradation of pollutants. A biofilter contains filter materials on which microorganisms are immobilized to form a biolayer. Biofiltration experiments were conducted using laboratory-scale biofilters and pilot-scale biofilter unit packed with a special processed wood bark on which a suspension of microorganism consortium isolated from biological sludge of wastewater treatment station in Slovnaft, Inc. was added. Parameters, including contaminant concentration, bed moisture content and pH, nutrient availability, number of microorganisms, retention time, efficiency of VOC removal were regularly controlled, evaluated and adjusted to the optimal values. A pilot-scale biofiltration unit for the optimization of process parameters direct in the locality of contaminated air occurrence was constructed. For this purpose, the biofiltration unit was built in caravan providing for the mobility of biofiltration unit. This system consist of three main component parts such as air ventilator, moisture column and own biofilter installation. The level of degradation of individual hydrocarbons, e. g. benzene, toluene, xylene, ethanol, acetone, styrene as well as mixture of solvents by the pilot-scale experiment was tested.*
Key words: *biofilter, biodegradation, VOC*

Introduction

The chemical process industries are facing increased regulation of hazardous air pollutants for the rest of this decade and beyond. These regulations will require that sources previously exempt from control or where controls have not been cost effective in the past must now act to reduce emissions [6].The new regulations will impact sources ranging from paint spray booths, with high-flow, low-concentration emissions, to processes emitting chlorinated organic species, which have always been a special emission control problem. Next decade will be a time of increasing development and refinement for hazardous air pollutant emission control needs and maintain continuous compliance with all regulatory requirements [7]. The control of hazardous air pollutant emissions, also known as air toxics, from industrial facilities is becoming increasingly important and expensive to the chemical process industries. Increasingly stringent regulatory requirements for air emissions have stimulated research efforts to improve conventional and develop more efficient and cost-effective control technologies in compliance with environmental objectives.

Biofiltration

Recently, biofiltration more and over competes with all the technologies that can be found in industry such as incineration, adsorption, catalytic oxidation and scrubbers - conventional methods for hazardous air pollutant removal. Since the mid 1980s, biofiltration technology for treatment of off-gases containing odours or low concentrations of volatile organic compounds (VOC) and other hazardous air pollutants has been established in Europe as an often cost-effective and environmentally benign alternative to combustion and sorption technology [5,10].

Biofiltration, unlike more traditional technologies destroys the contaminant and offers a potentially feasible, environmentally friendly and cost-effective alternative solution. Biofilters are most commonly used to remove odoriferous compounds and VOCs [1]. They are reactors packed with a wet material (e. g. compost, peat, or perlite) through which (humid) polluted air is passed. Biofiltration can be described as a process that utilizes microbial activity for the aerobic degradation of pollutants. Microorganisms are immobilized on a filter materials to form a biolayer. When waste gases pass through the reactor, target pollutants are transported into the biofilm and are utilized as carbon or energy sources by the microorganisms. In the biofilm, the VOC is degraded by the microorganisms to carbon dioxide, water and biomass. Advantages of biofiltration process are that process works at usual temperature (10–40°C) and atmospheric pressure. In addition, packed biofilter material requires no regeneration. Biofilter equipment demands low investment and operating costs, minimal maintenance, reliable operational stability and high removal efficiency for VOC concentrations less than 1000 ppm. Furthermore, biofiltration offers the added advantage of being a benign treatment technology. It is characterized by low overall energy requirements, no secondary pollutant discharge, absence of chemical reagents and no cross-media contamination.

It is generally accepted that biofiltration is capable of degrading hydrosulphide, carbon disulphide, ammonia, small organic sulphides, light aliphatic hydrocarbons, styrene and the others [1,2,3]. Some compounds show an inhibiting effect on the activity of microorganisms being used, in spite of this effect it is possible to reach out the efficiency of biofiltration up to 99% for odoriferous compounds and 90% for VOCs. Biofiltration has already been well established as an air pollution control alternative in Europe, Japan, Canada, U. S. A.

Operation Options for Biofilters

The technology of biofiltration with a principal view to hydrocarbons removal from contaminated air has been solved at the Department of Biotechnology and Toxicology, Development of Biotechnologies Slovnaft VÚRUP, Inc. Laboratory and pilot scale experiments confirmed known information and opinions from operation of industrial biofilters. The most relevant to biofilter performance has been reported following:

1. Filter media

An important factor affecting biofilter performance is choice of packing material which can provide the microorganisms with sufficient nutrients. Therefore, materials with a high content of organic compound are preferable choices for filter material. An important prerequisite for optimum biofilter is a suitable balance of the following characteristics of the carrier substance:

* regular even structure with a large surface area and good adsorption characteristics,
* sufficient voids,
* large concentration of organic material,
* good water retention,
* pH buffering capacity,
* low rate of decomposition of filter material.

Basically, this requirement is met by compost, bark and peat products [9]. In addition to the above-mentioned organic materials, inert substances such as granular activated carbon, lava rock, porous clay and polystyrene spheres may be also used. The optimum quantity and activity of the microorganisms are guaranteed only when certain ambient conditions are maintained within certain extremes inside the layer (moisture, pH-value, oxygen content, temperature, nutrients).

2. Physical-chemical interactions

The reaction rate of biofiltration process may depend on the concentration and type of waste gas components, activity of the microorganisms on the filter media in use, the temperature, the moisture content of the waste gas and of the filter material, the pH value. If the biological reactions proceed comparatively rapidly, then transport processes of the reactants from the gas phase on the inner surface area are also very important [8].

3. Design

The height of the carrier material is determined by the residence time of the waste gas within the carrier material, and by the filter load. Minimum carrier heights specific to the type of the filter material introduced are required for the achievement of a constant flow through the filter and for the avoidance of perforation. In the case of single-level filters, a height of at least 0,5 m is recommended [9].

4. Moisture

Among other conditions for perfect operation a sufficient moisture content in the filter layer is necessary. The moisture content should be held between 30% and 60%, depending on the material [1,5,9]. Moistening equipment must be operated in such a way that the moisture content stays within the indicated limits at any point of the filter layer. The construction of the filter must provide draining of the excess water.

5. Culture enrichment

In some cases, sufficient quantities of microorganisms are available in the filter material to constitute an active culture. In case inert filter bulks are employed or in case a higher efficiency is desired or a reactivation of the culture after extended interruption of operations is required, it may be sensible to enrich the culture. If the components of the waste gas and the means of their decomposition are known, it may be possible that sludges from the sewage treatment plant of the business itself or other biologically active material can be used for this purpose.

6. pH

Most microorganisms capable of degrading VOCs show optimum growth at pH values in the biofilm of between 6,5 and 7,5. To buffer acidic by-products in the media and maintain a neutral pH, alkaline buffers to the filter media may be added, usually calcium carbonate, dolomite or sulphur.

7. Temperature

Temperature also has a significant effect on biofilter performance. Optimum off-gas temperature ranges between 20–40 °C [4].

8. Nutrients

Compost – based media usually supply sufficient quantities of inorganic nutrients for growth, primarily nitrogen, potassium and phosphorus. It is necessary to provide the microorganisms with additional nutrients during operations if inert materials are used.

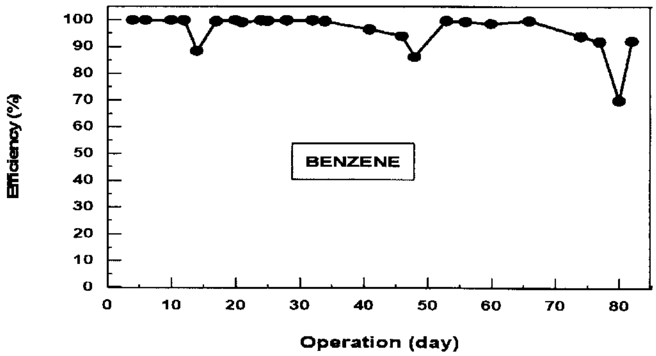
Laboratory Scale Biofilter Design and Operations

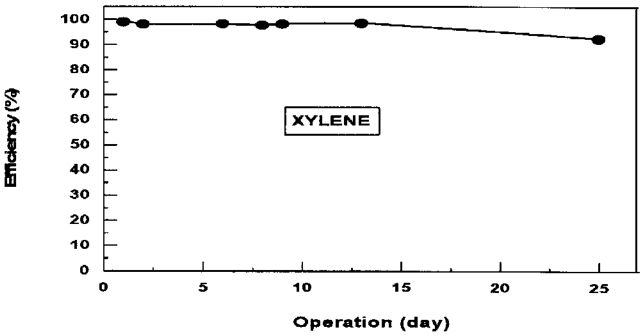
The biofilter was a glass column with a total packing volume 500–1000 ml. The packing material was contained in a chamber supported by a sieve plate. Inlet air stream passed through 250 ml bottle containing water to provide humidification and subsequently was contaminated with vapours of tested hydrocarbons. Biofilters were packed with cured wood bark, pH of bark was adjusted with calcium carbonate to maintain maximum biological activity. For most applications, the moisture content at which optimum sustained performance is achieved was between 50–62 %.

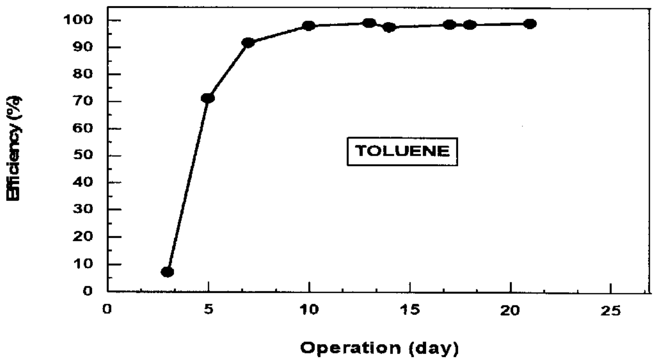
The nutrients were added periodically on the top of the biofilter in the ratio C : N : P= 100 : 1-10 : 0,3–1,4. The

Table 1. Comparison of biofiltration process parameters for tested VOC

Tested VOC	Operation [day]	Inlet [mg.m^{-3}]	Residence time [s]	Loading rate [g.h^{-1}.m^{-3}]	Efficiency [%]
benzene	82	767,1	45,3	58,5	96,0
toluene	16	392,9	43,4	31,8	97,5
o-, m-, p- xylene	25	300,8	44,9	23,5	97,3
styrene	119	219,5	49,7	15,4	96,5
ethanol	26	919,3	43,3	74,9	98,1







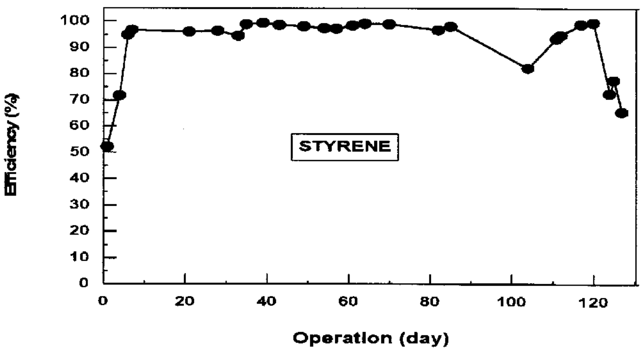


Figure 1. Comparison of degradation efficiencies of laboratory biofilters

packing material was inoculated with a microbial culture isolated from the wastewater treatment plant of refinery Slovnaft and adapted to a various sources of hydrocarbons. The inoculum was poured onto the packing from the top, collected at the base and recycled several times in order to ensure homogeneous distribution of the microbial population inside the filter bed.

Gas analysis were performed by means of a total hydrocarbon analyzer (Bernath Atomic, model 3005) equipped with a flame ionization detector.

The efficiency of the waste gas purification in material-specific measurements is the difference of the mass portions of one or more defined waste gas components upstream and downstream of the biofilter, related to the mass portion of this component/these components in the crude gas.

This section describes results and observations of the performance in reducing of chosen volatile organic compounds by laboratory biofilters. The possibility of removal of benzene, toluene, xylene, styrene and ethanol

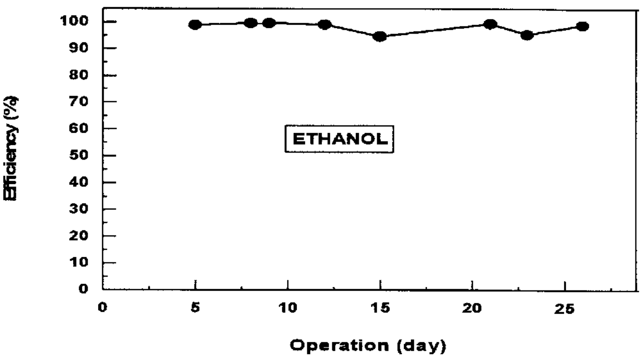


Figure 1. – cont. Comparison of degradation efficiencies of laboratory biofilters

are referred. Operation time of biofiltration was 16–119 days, inlet concentrations of tested VOC 219,5–919,3+ mg/m^3, residence time 43,3–49,7 s and loading rate 15,4–74,9 g/hr/m^3 (Table 1). By this operating options, substantial reductions of compounds and high efficiency was achieved, in the range of 96–98%. Comparison of degradation efficiencies of laboratory biofilters for individual VOC are presented in graphic form (Figure 1).

Table 2. Operating parameters of mobile biofilter – pilot scale experiment.

Tested VOC	Operation (day)	Inlet temperature (°C)	Outlet temperature (°C)	Flow rate (dm^3/min)	Pressure drop (Pa)	Inlet (mg org. C/m^3)	Outlet (mg org. C/m^3)	Efficiency %
Xylene								
	0	26,0	26,5	784	20	466,3	–	–
	8	25,0	26,5	856	400	408,4	49,8	87,8
	15	28,0	29,0	820	270	102,9	12,9	87,5
	22	22,0	23,0	820	250	402,0	32,2	92,0
Mixture of solvent								
	6	25,0	26,0	784	550	138,3	20,9	84,9
	13	24,0	25,0	856	480	588,5	53,1	91,0

Pilot Scale Experimental Set-up and Procedure

Pilot scale experiment was realized in paint-industry company. The possibility of removal of organic solvents exhausted directly from the off-gas of production hall was tested. The mobile pilot scale biofiltration unit was connected, to optimalize process parameters in the locality of contaminated air present. For this purpose, the biofilter has been built in caravan providing for the mobility of biofiltration unit.

Packed-bed volume was 0,8 m^3, bed height 1 m, what render to treat the contaminated air flow 48–96 m^3/hr. There are no special demands for inlet off-gas in view of its temperature and moisture, they are automatically adjusted. However treated air could not be chemical aggressive or explosive. Mobile biofilter is provided with a simple measurement and regulation system to ensure the stabilization of temperature and moisture of off-gas, as well as automatic addition of evaporated water and the protection of heater in a case of water pumping failure. Technological equipment consists of following main components: 1) blower, 2) humidifier, 3) biofilter. An off-gas entering the filter media is exhausted by blower and subsequently humidified in the humidification column. The heated water basin is placed in the back of the humidification column. The water is electrically heated to required temperature. Evaporated water is regularly suplemented through solenoid valve to maintain a constant water level in the water basin. Prehumidified air of demand temperature enters the biofilter. Residence time is adjusted to 30–60 s. Treated air exits through the output piping system to the atmospheric air.

The level of xylene and mixture of solvent reductions by pilot scale biofilter has been examined. Inlet, outlet temperatures, flow rate, pressure drop, inlet, outlet concentrations and efficiency of biofiltration process during the pilot scale experiment are illustrated in Table 2. Prepared mixture of solvent (Table 3) corresponds to the present stage of paint industry company production program. Biofiltration of air contaminated with xylene was maintained for 22 days. Substantial reductions of examined compounds have been achieved with the pilot scale biofilter.The efficiency of pollutant removal consecutive increased to 92% by inlet xylene concentrations 103–466 mg org. C/m^3. After 22 days of biofilter operation, xylene was replaced with mixture of solvent. The efficiency of contaminant removal from off-gas reached out the levels 84,9–91 % by inlet concentrations 138-589 mg org C /m^3.

Table 3. Composition of tested mixture of solvent

Compound	% wt
gasoline fraction – white spirit	36,0
xylene	9,5
toluene	15,5
ethyl acetate	14,5
butyl acetate	16,0
methyl acetate	1,0
butanol	2,0
isobutanol	3,0
acetone	2,5

Conclusions

Results from laboratory scale studies indicate that biofiltration can effectively treat tested compounds. In this paper, selected biofiltration experiments were demonstrated by which the substantial reduction and longterm efficiency have been achieved. Valuable know – how with regard to adjustment of optimal conditions for biofiltration process have been obtained. The most relevant are the moisture of biofilter packing material and nutrients addition. The results of laboratory scale experiments verified in pilot - scale conditions. The obtained results have been in a good accordance with laboratory biofiltration experiences. It can be generally claimed that biofiltration is useful technology for above mentioned pollutants, in case when continual operation and concentration of pollutants in range cca 50 - 2 000 mg/m^3 of air is possible to consider.

We believe that technology of biofiltration will become an acceptable alternative for Slovnaft, Inc. in solving air pollution problems at the beginning of a new millennium.

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