Experimental research on VOC treatment by biofiltration

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Abstract

Experimental research is currently being conducted in the Air Study Laboratory (LEA) of the ENSGTI on the treatment of air containing volatile organic compounds (VOCs) by biofiltration technology. A pilot-scale biofilter unit was designed for this work. The experimental set-up consists of a high-quality glass column containing a natural organic filter material with a microbial strain population and nutrients. The three compounds being studied are toluene, acetone and trichlorethylene. The objective of this paper is to summarise some experimental results concerning the biofilter operation limits at various air flow and constant mass loading; the characterization of the microbial strain population responsible for VOC degradation; the moistening optimization of the biofilter; the ability of the biofilter to restart after a shutdown of the system.

The methodology used consists in directing an air flow fed with three VOCs passing through the filtering material. The concentration of VOCs in the contaminated air at the inlet, outlet and at different levels of the column are measured with a gas chromatograph (FID). A constant volume of percolate is sampled every two days. Measurements are taken every day on the column: room temperature and pressure, pressure drop, hygrometry, pH and percolate volume. The metal content and the total organic carbon (TOC) are the major parameters which are analyzed in order to verify that the biofilter is functioning. Results have shown an elimination of toluene and acetone, about 90% and 100% respectively after one week of operation.

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1 Introduction

Biofiltration is a biological control process in which gases are treated during their transportation or passage through an active porous media. Among the most important air pollutants, Volatile Organic Compounds (VOCs) are a matter of environmental concern at this time. For example, VOCs are causing ozone formation at ground level. In Europe, theses compound emissions are already strictly regulated because of their direct danger and impact for the health of the population, even at low concentrations. VOC terminology covers all volatile organic compounds which can evaporate at ambient temperatures and exist in the atmosphere in gaseous form or adsorbed on the surface of particles [1]. Many of these VOCs present in the atmosphere are extremely toxic. VOCs which are diffused in the residential ambient atmosphere come from synthetic materials or composites such as aerosols, paint, cleaning agents, air conditioning systems, office furniture and cigarette smoke.

The various known technologies which have already been applied for the control and elimination of VOCs are as follows: incineration, condensation, catalytic thermal oxidation, chemical cleaning, absorption by water washing, activated carbon adsorption and chemical scrubbing. In general, such operations are often very expensive. Over the last few years, searchers have focused their efforts on studying biological systems in order to propose a clean technology to industry. Biological techniques have recently been widely developed in the world [2]. The application of biotechnology is a particularly promising emerging technology for air pollution control particularly when the pollutants are vapours of organic compounds present in air streams at low concentrations. In addition, biological processes are less costly and environmentally viable compared to conventional technologies since they don't pollute water, air or soil which may require extra treatment [3]. Among all gas biological treatments that exist, biofiltration is the most attractive. It is a cost effective, **clean technology** and the equipment is simple and requires little energy [1].

Over the last twenty years, biofilters have been developed for eliminating specific chemical compounds, from industrial plants [4]. This new technology has been successfully applied on different levels to odour control, VOC reduction and toxic gaseous emission control, from both industrial and public sources [5]. For economic reasons and environmental advantages, the biofilters market is on the rise.

The biofilter system is a fixed bed of solid porous material in which micro-organisms grow on solid particles and degrade the organic pollutants. The polluted air stream is fed into the biofilter and passes through the packed bed provided with micro-organisms and essential nutrients. Nutrients might have to be added for micro-organisms to develop properly. Thus, the biological activity of the microbial population rises inside the packed bed resulting from an accumulation of micro-organism layers around solid particles, forming the active *biofilm*. This *biofilm* is the support of all physical and biological phenomena involved during the elimination or air contaminants. The flow of polluted air between the gas phase and the *biofilm* permits a continuous mass transfer process

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between the gas phase and the *biofilm*. Gaseous pollutants are carried from the gas phase to the *biofilm* where they are biodegraded continuously into water and carbon dioxide and used as the essential carbon source for microbial growth. Biofiltration potential is strongly affected by the molecular structure of pollutants and their concentration in the gaseous effluent [3].

This article aims to describe in particular the experimental work: the laboratory experimental apparatus, the methodology used, the setting up of instruments for studying biofiltration and its conditions used, the experimental parameters studied as well as the results obtained during the degradation of trichlorethylene, toluene and acetone diluted in an atmospheric media. Experimental tests performed are related to the design and operational parameters which depend on a correct biofilter operation such as chemical properties of the media, humidity, pH, temperature, availability of nutrients and pressure drops.

2 Experimental Section

2.1 Material and Analytical Methods

Experiments on the degradation of VOCs were conducted at Tarbes on a pilot-scale [6]. Figure 1 shows a scheme of the experimental biofiltration column. Figure 2 presents a photo of the whole experimental installation. The pilot consisted essentially of a four stages biofiltration column made of glass (EIVS glass) and its associated air moistening system. The inner diameter and the overall height of the pilot are respectively 10 cm and 2,21 m. The biofilter is 1 m in height with a cross section area of 0.79 m^2. The total packing volume of the biofilter is 7.9 L. In the lower base of the column, the biofilter bed is maintained by a PFTE grid supporting one meter height packing. The free area through the grid should always be greater than the external porosity of packing in order to avoid pressure drops through out the grid. External porosity of the material used is estimated to be 77%. Then free area proportion of the grid should be not less than 90%. A layer of small stones are placed just above the grid to reduce the possibility of plugging. The grid should be made in PFTE as it will be in contact with hydrochloric acid from the degradation of compounds containing chlorine. The effluent to be treated is created by compressed air flowing through a moistening tower for complete saturation with water before entering the top of biofilter. Mixture of pollutants is injected with a syringe-pump through an 4 mm orifice placed inside glass tube connected to the top of the biofilter. Flow regulation is performed with a flow meter.

Periodic feeding with a mineral solution each week is made in the biofilter, to bring some mineral supplements and to be sure of the humidity in the media. The choice of the watering device is the key for the successful operation of the biofilter. This shower head should be chosen properly in function of the height, diameter and volume of the biofilter. The porous media used in this study is ABONLIR organic fertilizer packing from Bilbao, Spain. From the outlet of the biofilter, the purified air is directed to the cooper hood.

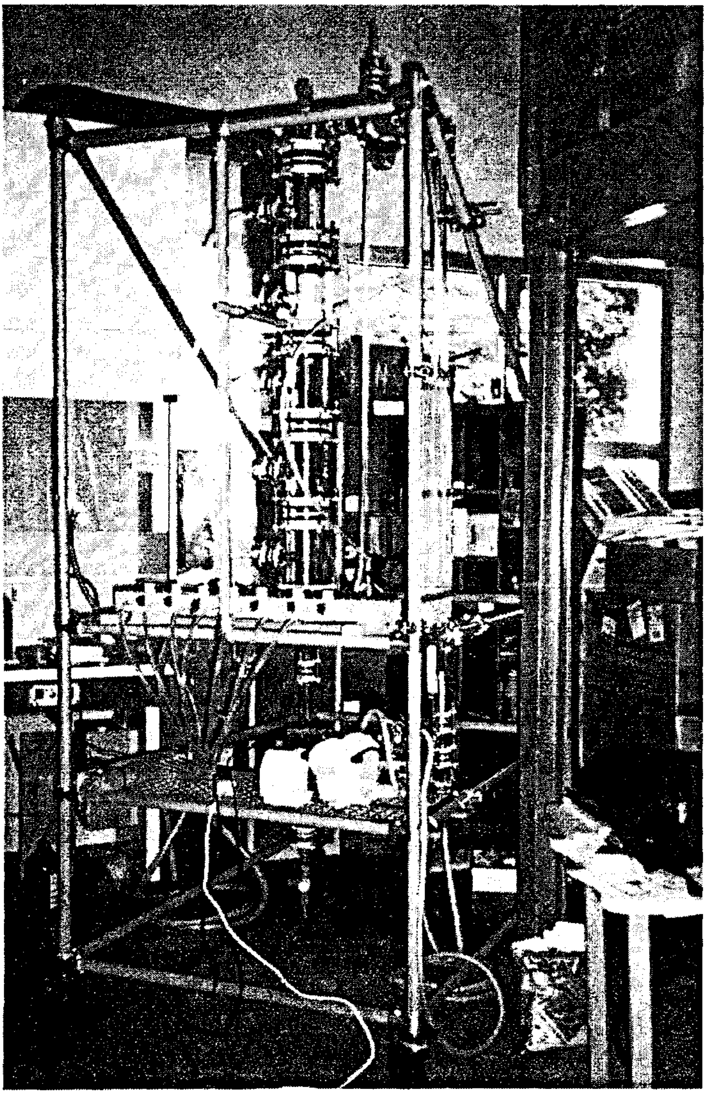

Figure 1 : Photography of the Biofilter

Compressed air has been de-oiled and purified before being used for the pilot and the gas chromatography analysis. Compressed air is produced by a membrane pump equipped with a activated carbon filter, a drying system and a pre-filter. The concentration of pollutants is analysed with a gas chromatography (GC) equipped with a flame ionisation detector (FID) provided by Hewlett-Packard.

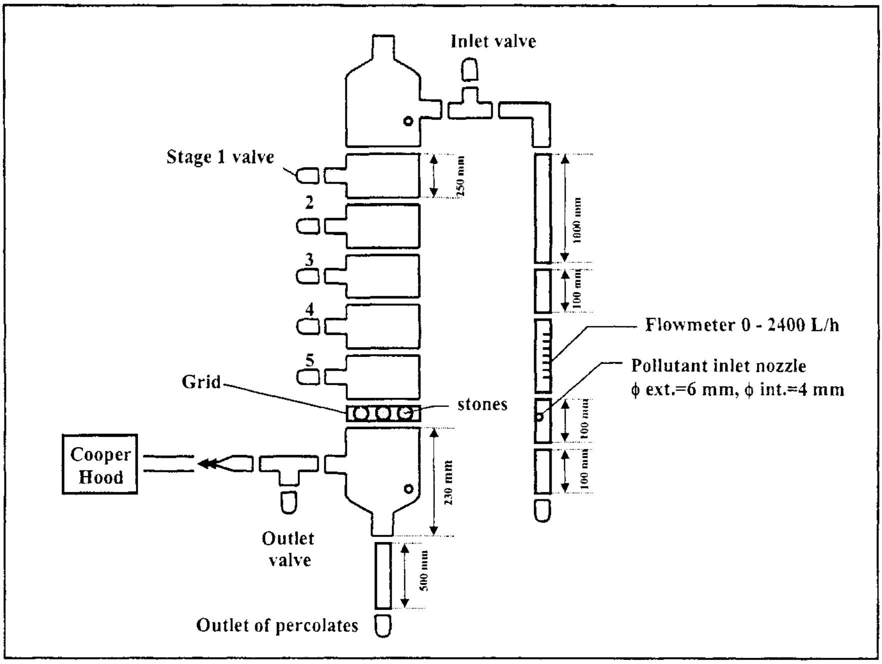

Figure 2 : Biofiltration column scheme

2.2 Analytical Methods and Operating Procedures

The methodology used for this experimental research is based on the degradation efficiency study of three VOCs (toluene, acetone and trichlorethylene) diluted in an air flow inside the biofilter (Fig. 1). The pilot is first started with a pressurised clean air flow, to check for possible leaks. Then the VOC mixture is injected and the VOC concentration is analysed by GC at every sampling valve all along the column. Then the air is humidified by bubbling through a sufficient amount of distillate water, to check the influence of humidity on GC analysis. Concentration of VOCs entering the column should be constantly verified before starting the biofilter. The biofilter was first started without any sowing and nutrients, because the packing already contains mineral compounds, trace elements and one bacteria source. VOC concentration in polluted air at the column inlet, at the outlet, and at four different column levels are analysed (respectively 100, 350, 600, 850, 1100 mm from the biofilter top). Every sampling valve is connected to a centralised sampling box which send the samples to the GC. Humidity, temperature and pH are also measured continuously. Down the column, a straight length of 500 mm has been implemented to take a daily percolate sampling for physico-chemical analysis.

Optimal humidity in the media is to be screened in order to raise the overall efficiency of the biofilter. An electronic device ensures that the packed bed is watered periodically. This optimal humidity has been estimated in function of

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packing porosity and water content. An evaluation of air flow hydrodynamics through the column has been made. The watering system - a shower – has been implemented at the top of the column. With this system, quick packed bed humidification can be made to avoid any drying or plugging of the bed. Several groups of micro-organisms are involved in the degradation of gaseous pollutants inside the biofilter, including bacteria, actionicetes and mushrooms. To avoid termination of any micro-organisms through lack of oxygen and biofilter drying, periodic aerations are made and nutrients are injected during shutdown. Table 1 gives, for each experimental sequence, the watering frequency (f), the watering volume added (Ve) and the water column height He used for air humidification by bubbling.

	F (number/day)	Ve (litre/day)	He (cm)
27/07/00-09/10/00	6	1.32	-
10/10/00-16/10/00	6	1.32	70
17/10/00-19/10/00	6	1.32	30
20/10/00-23/10/00	1	0.35	30
24/10/00-today	1	0.35	30

Table 1

Initial conditions for the study of the degradation performance of biofilter pollutants are as follows : Air flow speed (Vo) of 100 m/h, air flow rate (Qo) of 0.785 m^3/h, VOC concentration (Co) of 375 mg/m^3 of air, VOC residence time inside the bed of 36 seconds. These parameters were chosen to be similar to industrial emissions conditions. Density of the VOC solution was measured at 1030 kg/m^3. The stationary state of the biofilter was reached around 45 days after it was started. The more relevant measurements made during the experimental study of the biofilter are as follows : Air watering at the inlet and outlet of the column, pH and volume of percolated water, pressure drops across the bed, air flow rate, degradation efficiency for each of the three pollutants and at each stage of the column (inlet, outlet including six sampling valve regularly disposed) and sampling biofilter material. The biomass activity was evaluated through analysis with an electron scan microscope and a counting technique giving the type of micro-organisms living in the biofilter and the number of cultivable bacteria by gram of biofilter which is around 10^8.

3 Results and Discussion

Figures 3, 4 and 5 show respectively the air flow rate variation (Qa), the water volume (Ve) retained by the biofilter and the pressure drop variation over time. According to figure 5, maximal pressure drops occurred when the water volume retained by the biofilter was also to its maximum level. Important fluctuations for the Qa and Ve parameters can be seen, as it is very hard to keep a constant air flow while the watering content of the porous media is highly variable in time. The bacteria development and its contribution to porous media partial plugging can also explain these air flow rates (Fig. 3), water volume retained (Fig. 4) and pressure drop variations (Fig. 5).

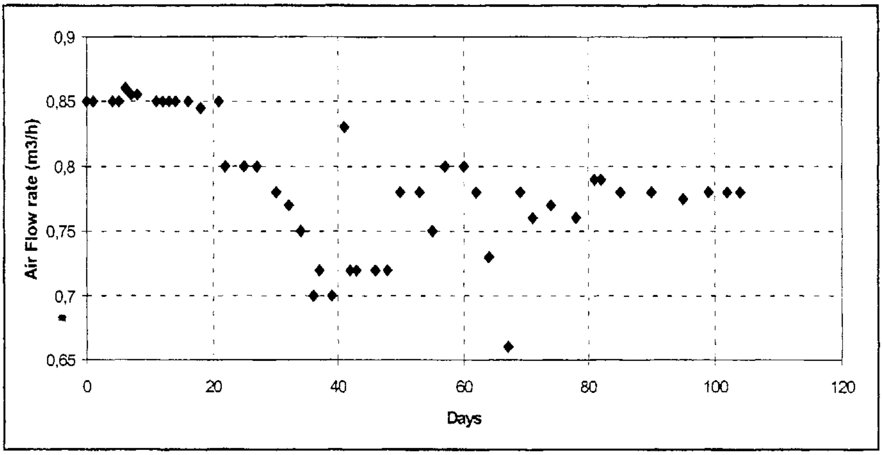

Figure 3 : Air flow rate variation over time

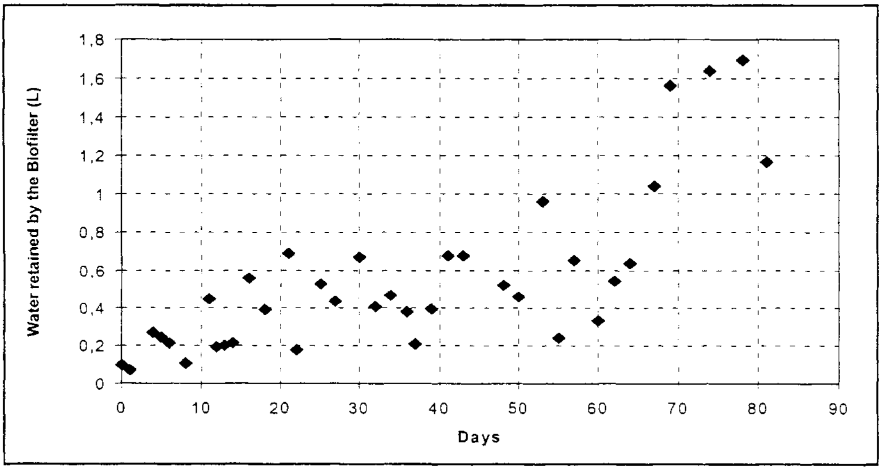

Figure 4 : Water volume retained variation over time

pH of percolates collected at the biofilter outlet do not fluctuate too much over time (Fig. 6), from 8.1 to 8.9, this small variation depends on the physico-chemical, bacterial and hydrodynamic state of the biofilter. It shows that the natural porous media possesses a good buffer capacity. After 100 days of operation, a pH lowering is observed , because probably of the degradation of trichlorethylene into hydrochloric acid. When pressure drops are low, the biofilter is operating well, but a quick increase in pressure drops after 90 days of operation means a partial plugging of the biofilter (Fig.5). By sampling at each stage of the column, and also at the outlet, the three pollutant concentrations were measured regularly by GC.

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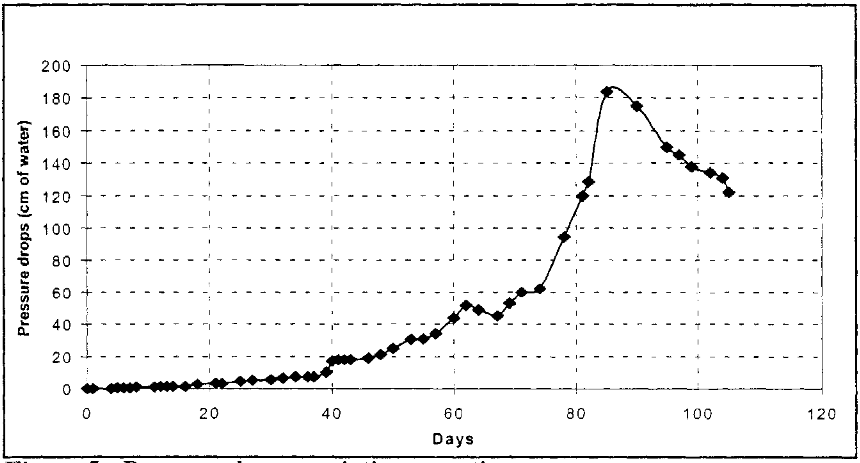

Figure 5 : Pressure drops variation over time

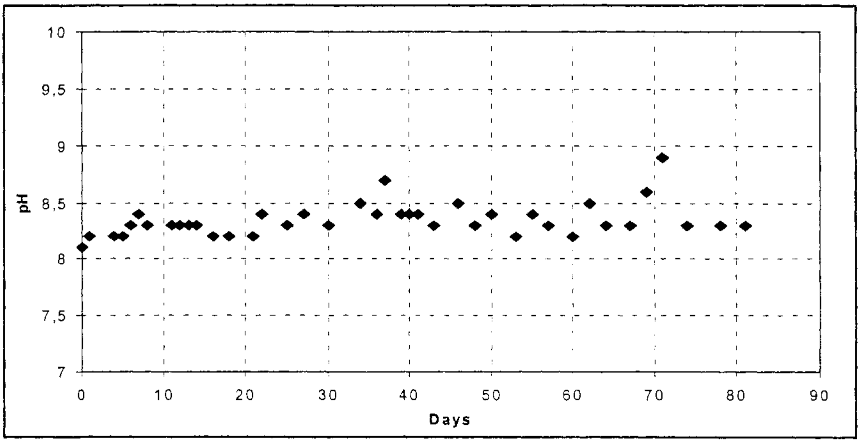

Figure 6 : pH variation over time

The biofilter efficiency for the degradation of the pollutants at each stage was then calculated in function of time. Because degradation efficiency was followed throughout the various stages, this calculation gave some indication as to the residence time required for the complete elimination of each pollutant and will help the optimisation of the column design. Figure 7 shows the degradation efficiency variation for each of the three pollutants at stage 3, and Figure 8 shows it at the column outlet. According to figure 7, acetone elimination by biofiltration is quite completely reached at stage 3, as the maximum level of toluene degradation is occasionally reached at 90% at the outlet of the column, depending on the humidity and the bacterial state of the biofilter. The trichlorethylene degradation efficiency remains low, under 25%, depending on the bacterial state and the hydrodynamics of the porous media.

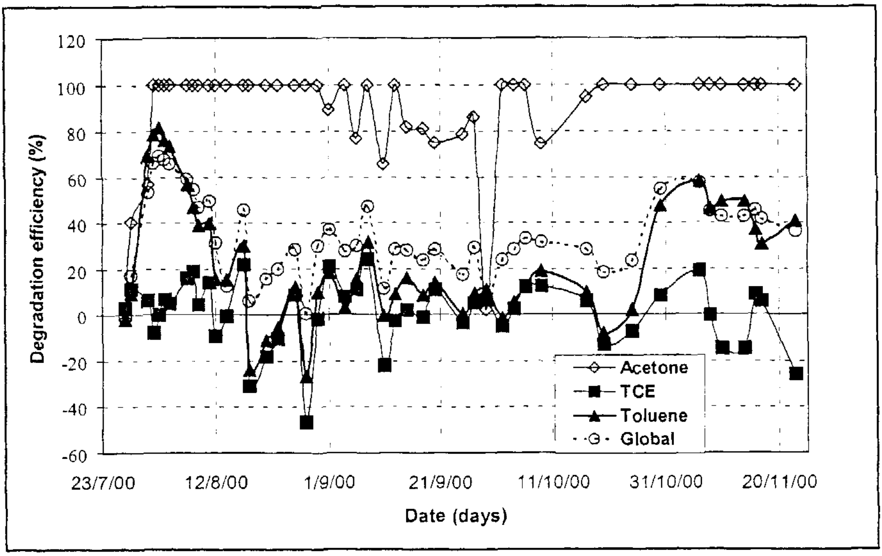

Figure 7 : Degradation efficiency at stage 3 over time

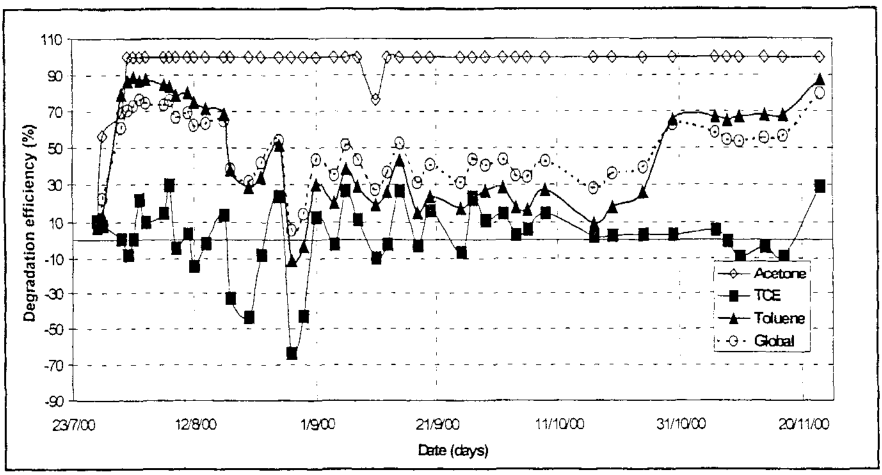

Figure 8 : Degradation efficiency at the column outlet over time

4 Conclusion

Biofiltration is very advantageous for the treatment of gaseous pollutants, particularly VOCs, compared to usual technologies. The preliminary experimental pilot plant from the laboratory gave in five months of operation the opportunity to assess the biofilter efficiency for the degradation of three pollutants (acetone, toluene and trichlorethylene) depending on various physico-chemical, bacterial and hydrodynamic conditions. This experimental research shows that acetone degradation was excellent (100%) and toluene degradation was satisfactory (90%) under specific conditions of bacteria activity and watering level in the porous media. The biofiltration performance for trichlorethylene was quite limited. Experiments using specific bacteria are planned to improve the degradation of trichlorethylene.

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