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Section: Environmental protection

Analysis and assessment of biofilter packed with different wood waste charges for toluene removal

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Abstract

Biological treatment of the polluted air stream holds promise for removing volatile organic compounds (VOCs) and odors, thereby not only potentially reducing the overall toxicity of the waste air emitted during various production processes, but also improving the life quality of residents living near the industrial areas companies. The main aim of this work was the analysis and assessment of toluene removal from air using biofilter packed with a mixture of wood waste. The results of this work show that the small–scale biofilter with various coniferous and deciduous wood waste charges is capable of efficiently removing toluene from the polluted air stream. The removal efficiency up to 92% was determine when treating the polluted air stream with the initial pollutant concentration of 5–20 mg/m^3 when using biofilter packed with 10–20 mm fraction size wood waste charge composed of 70% coniferous wood, 30% deciduous wood. The measured porosity of this charge was equal to 46%.

Keywords: biofilter; toluene; volatile organic compounds; wood waste charge.

1. Introduction

Biofiltration is a process that uses microorganisms (degraders) to oxidize volatile organic compounds (VOCs) and oxidizable inorganic vapors and gases in an air stream. Biofiltration is an extension of natural purification processes [1]. It is effective and economical for low concentrations of a contaminant in large quantities of air. The contaminants are sorbed from gas to an aqueous phase where the microbial attack occurs. Through oxidative and occasionally reductive reactions, the contaminants are converted to carbon dioxide, water vapor and organic biomass. These air pollutants may be either organic or inorganic vapors and are used as energy and sometimes as a carbon source for maintenance and growth by the microorganism populations [2]. In general, the microbes used for biological treatment are organisms that are naturally occurring. These microbial populations may be dominated by one particular type of contaminant synergistically [3].

Biofiltration uses microorganisms fixed to a porous medium to break down pollutants present in the air stream. The microorganisms grow in the biofilm on the surface of a medium or are suspended in the water phase surrounding the medium. The filter–bed medium consists of a relatively inert substance (compost, peat, pine bark, wood waste, etc.) which ensure large surface attachment areas and additional nutrient supply.

As the air passes through the bed, the contaminants in the air phase sorb into the biofilm and onto the filter medium, where they are biodegraded. Biofilters are not filtration units as strictly defined. Instead, they are systems that use a combination of basic processes: absorption, adsorption, degradation and desorption of gas–phase contaminants [3].

To sum up, the particular contaminant of interest must be biodegradable and non–toxic for biological air treatment to be successful. The most successful removal in gas-phase biofilters occurs for low molecular weight and highly soluble organic compounds with simple bond structures. Compounds with complex bond structures generally require more energy to be degraded, and this energy is not always available to the microbes. Hence, little or no biodegradation of these types of compounds occurs. Instead, microorganisms degrade those compounds that are readily available and easier to degrade [4]. Organic compounds such as alcohols, aldehydes, ketones, and some simple aromatics demonstrate excellent biodegradability. Some compounds that show moderate to slow degradation include phenols, chlorinated hydrocarbons, polyaromatic hydrocarbons, and highly halogenated hydrocarbons. Inorganic compounds such as hydrogen sulfide and

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ammonia are also biodegradable well [3]. Certain anthropogenic compounds may not biodegrade at all because microorganisms do not possess the necessary enzymes to break the bond structure of the compound effectively.

The main aim of this work will be the analysis and assessment of volatile organic compound removal from air using biofilter packed with a mixture of wood waste. The main tasks to achieve this aim will be:

- to determine the efficiency of biofilter depending on volatile organic compound (toluene) chemical nature, concentrations, the height of biofilter charge and gas flow rate;
- perform the analysis of biofilter packed with different wood waste material effectiveness for removing volatile organic compounds from air;
- to perform mathematical modeling according to the results of investigation.

This work will combine theoretical, experimental investigation into biotechnologies, determination of filter efficiency for removing toluene from polluted air stream, investigation of biologically activated wood waste charges of different fractions and the modeling of biofiltration processes.

2. Methodology

2.1. Experimental setup

The biofilter used to carry out the experiment was developed at the Department of Environmental Protection of Vilnius Gediminas Technical University and patented by National Patent Bureau of the Republic of Lithuania in May 2003 [5]. This biofilter was originally developed to carry out experiments with activated pine bark as its medium, but other materials may also be used for experimental purposes.

When purifying air from volatile compounds of organic nature, flow of polluted air is blown through all five layers of biomedium by means of ventilator. There are dampers installed in the inlet and outlet ducts of the filter to adjust air flow (from 58 to 145 m^3/h) and flow velocity (0.01 to 0.1 m/s). The temperature is maintained at 30 ºC in the filter charge, so the medium is heated by two heating elements installed at the side walls of the filter. Prior to starting the biofilter, the medium was moistened, biogenic elements were added, and it was biologically activated by blowing organic pollutants through the medium. When the air purifying process is in progress, 20 *l* of water is consumed per day to maintain humidity of 60% in the whole volume of the medium (0.18 m^3). When the filter isn't operated, activity of microorganisms in the charge decreases, and water consumption goes down to 10 l [5].

It is important to evaluate factors, which influence the efficiency of biological air treatment: pH, moisture content, temperature, concentration of pollutants and the speed of flue gas. The supervision of biofilter exploitation was performed one time in a week. The biological air treatment process was started after microorganism's activation, which continued about three weeks. In activation process, pollutant was heated by using small electric oven placed below the biofilter inlet duct and evaporated into the inlet. Moisture content in layers was maintained at 60%. Water solution with mineral saltines was spread on the wood waste charge. One liter of water solution with chemical reagents: KCl (0.5 g); $Fe_2(SO_4)_3$ (0.1 g); KH_2PO_4 (1 g); $NaNO_3$ (0.1 g) was used. Moreover, pH was supported neutral instance (pH ≈ 7), because natural biomedium suits for the spontaneous existence of microorganisms the best [5].

2.2. Equipment

The main equipment used in the experiment was:

- velocity meter TESTO-452, the interval of flue gas measurement up to 60 m/s;
- measurer of pressure TESTO-452, the range of pressure measurement up to 1000 Pa, errors 10 Pa;
- gas chromatograph "Hawlett Packard Model 5890" flame ionization detector accuracy 4·10–9 mg/s;
- analytical scale VLR-200, the interval of measurement is 0–100 g. Error is 0.00005 g.

2.3. Materials

The main materials chosen for this work can be easily obtained whenever road constructions are being performed; a land is being deforested for construction, etc. The materials are abundant, and therefore, they can be easily applied in biofiltration process. The main materials chosen for this work will be:

- pine tree (*Pinus sylvestris*) branches without needles,
- fir tree (*Picea abies*) branches without needles,
- juniper tree (*Juniperus communis*) branches without needles.
- oak tree (*Quercus palustris*) branches without leafs,
- maple tree (*Acer platanoides*) branches without leafs,
- hazel tree (*Corylus avellana*) branches without leafs,
- asp tree (*Populus tremula*) branches without leafs.

Wood waste charge of different fraction size (10–20 mm and 20–50 mm) composed of 70% coniferous wood, 30% deciduous wood was used in the experiment.

The results from other case studies of wood waste usage as biofiltration media show that by using this material as bed media usually the volatile organic compound removal effectiveness of 90–95% can be achieved [6–9].

3. Results and their analysis

The efficiencies of this biomedia charge to remove toluene was determined at various flow rates ranging from 0.02 to 0.10 m/s and various heights of biomedia ranging from 0.15 to 0.75 m.

The overall removal efficiency of toluene in the bio-filter packed with first mixture of wood waste charge (70% coniferous wood, 30% deciduous wood) is shown in Figure 1. As mentioned before the pH value was kept approximately at neutral levels.

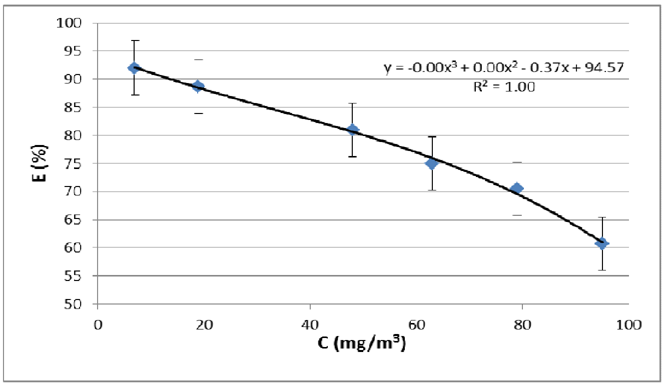

Fig. 1. Overall efficiency of toluene removal (fraction size 10–20 mm, P = 46%)

Figure 1 shows the overall removal efficiency of toluene for air stream when using biofilter packed with 10–20 mm wood waste charge composed of 70% coniferous wood, 30% deciduous wood. The measured porosity (P) of this charge was equal to 46%. All concentrations were measured three times and were estimated an average, which was used in graphics. As we can see from Figure 1, the biofilter is effective at treating an air stream from low concentrations of toluene. The removal efficiency up to 92% was determined when treating the polluted air stream up to 20 mg/m^3.

When determining the effectiveness of different fraction charges a dramatic drop in removal efficiency has been observed (Fig. 2). As we can see from Figure 2, the overall removal efficiency of toluene using bigger fraction wood waste charge has decreased from 92 to 84%. This result is given to the fact that the higher fraction has a bigger porosity value, and therefore, the contaminants are absorbed slower than compare to the smaller fraction wood waste charge.

In the experiment, the filter efficiency was also tested depending on the number of biofilter charge layers. The increase in the number of the layers from one to five resulted in higher efficiency of air cleaning due to a greater amount of the biomedium and higher concentration microorganisms. When the number of layers was increased up to five, efficiency of air cleaning at that same initial concentration was higher. Results of toluene removal efficiency depending on the layer height are given in Figures 3 and 4.

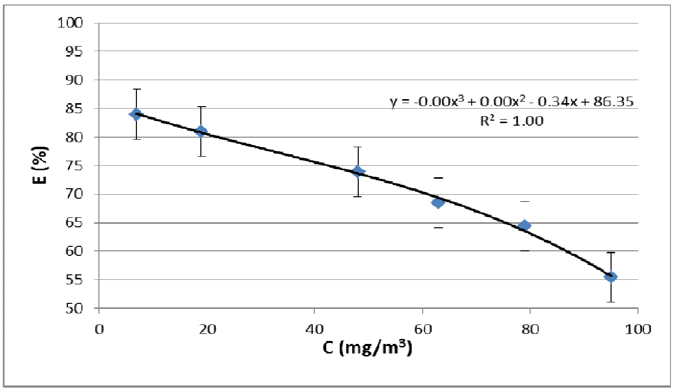

Fig. 2. Overall efficiency of toluene removal (fraction size 20–50 mm, P = 67%)

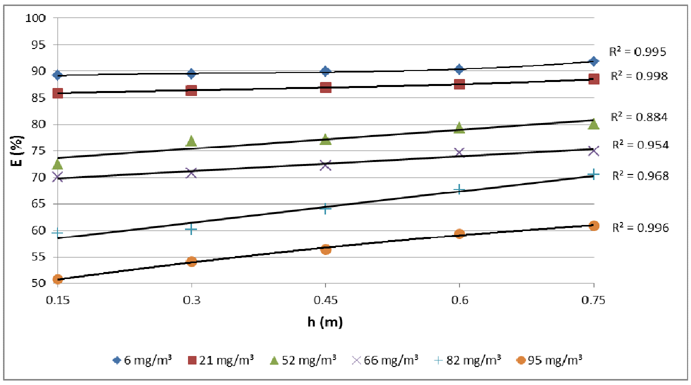

Fig. 3. Removal efficiency of toluene (fraction size 10–20 mm, P = 46%)

As we can see from Figure 3, injecting the air with lower concentration of toluene (from 6 to 32 mg/m^3), the air cleaning efficiency after one layer and after five layers hardly differed (3–15%). For example, the efficiency of air cleaning of toluene with the initial concentration of 6 mg/m^3 after one charge layer was 89.2%, after five layers it was 91.8%. Moreover, the efficiency of air cleaning of toluene with the initial concentration of 32 mg/m^3 after one charge layer was 82.5%, after five layers it was 85.1%. With the increased initial pollutant concentrations, biofiltration efficiency changed after one and five layers approximately 3%. The biggest change in efficiency is noticeable at higher values of initial concentration (e.g. starting from 52 mg/m^3), but the overall removal efficiency at such a concentrations is noticeably lower.

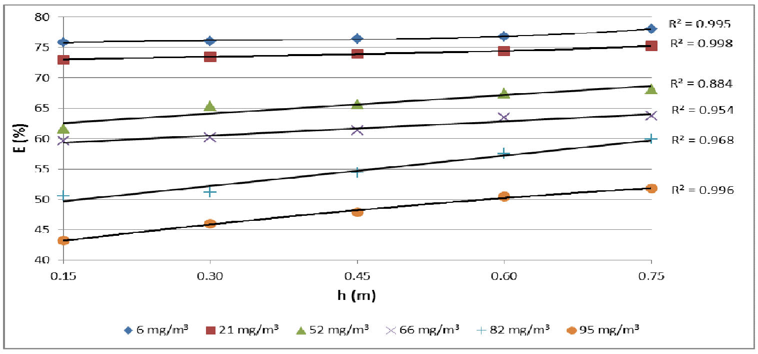

Fig. 4. Removal efficiency of toluene (fraction size 20–50 mm, P = 67%)

Figure 5 shows the results when measuring the efficiency of 10–20 mm fraction wood waste charge, which has porosity value of 46%. At the pH = 7 the filter efficiency of 92.10% is achieved with the initial concentration of 4 mg/m^3 and flow rate of 0.02 m/s. Accordingly, when the initial concentration of toluene is up to 23 mg/m^3, the air to be clean may be injected at the speed of 0.08 m/s and even at a higher speed, in which case the efficiency of air cleaning is 79.20%. If the speed of the airflow passing the filter is increased to 0.1 m/s without changing the mentioned-above test conditions (the initial pollutant concentration 92 mg/m^3), biofiltration efficiency goes down to 51.30%.

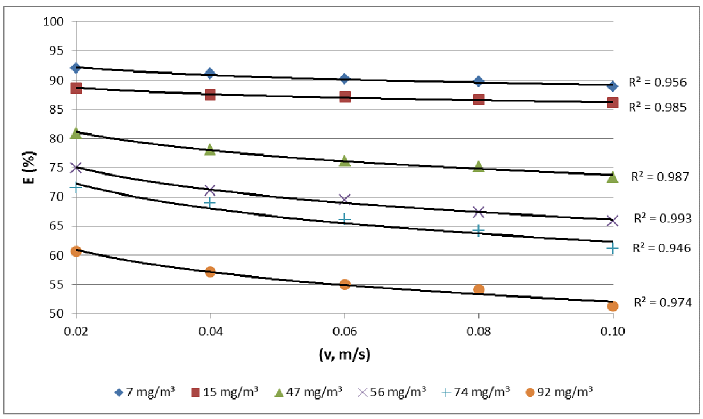

Fig. 5. Toluene removal efficiency according to polluted air stream flow rate (fraction size 10–20 mm, P = 46%)

Figure 6 shows that when comparing results to the higher fraction (20–50 mm) wood waste charge, the efficiency drops to 43.61%, when the maximum initial concentration of 92 mg/m^3 is present and the flow rate of 0.1 m/s is used. This can be concluded from the fact that higher porosity value of the bio-media lets the polluted air stream to pass more easily through it due to the fact that this charge has more voids in it and is less dense than the lower fraction size charge. The results of toluene removal show that it is more optimal to remove toluene from the polluted air stream at lower concentrations (up to 20 mg/m^3) using air low rate up to 0.10 m/s. The conclusion can be made that the lower the air speed the bigger the retention time of the pollutant in the bio-media due to the fact of the slower moving air stream. The lower air stream flow rate also indicated the decrease in slowing stream turbulence, which lets the contaminant distribute more equally in the investigated wood waste charge.

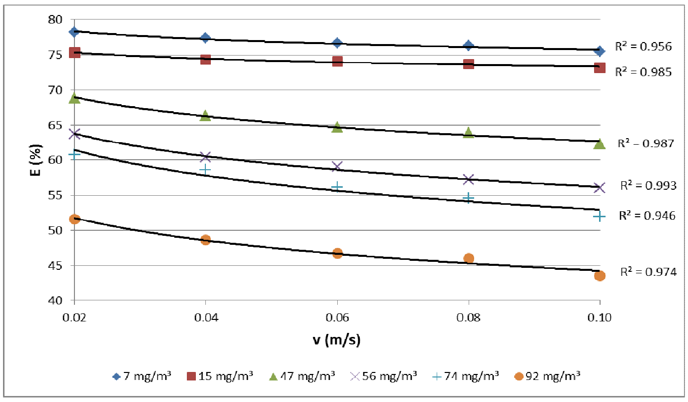

Fig. 6. Toluene removal efficiency according to polluted air stream flow rate (fraction size 20–50 mm, P = 67%)

The results of wood waste use in biofilter for toluene removal from the air stream are similar to those mentioned in case studies [6–11]. The small differences in biofilter efficiency can be explained by the chemical nature of toluene. Toluene is considered to be a mutagen and carcinogen and acts as a disinfection measure for microorganisms in higher concentrations. This is clearly shown in the results when the toluene removal efficiency drops drastically after reaching the initial pollutant concentration of 21 mg/m^3.

4. Biofilter and air flow modeling

In this work, a biofilter air flow modeling is being analyzed with the use of PHOENICS 3.5.1 computational and modeling program. The biofilter model (Fig. 7) itself consists of 5 biomedia sections, cylindrical inlet and outlet.

The biofilter size is 0.5×0.48×2.0 m. The height of each biomedia is 0.15 m. The inlet is situated below the first biomedia section and injects the air from right side of biofilter perpendicularly to the biofilter base plane (only in x direction). The outlet is situated at the top of the biofilter.

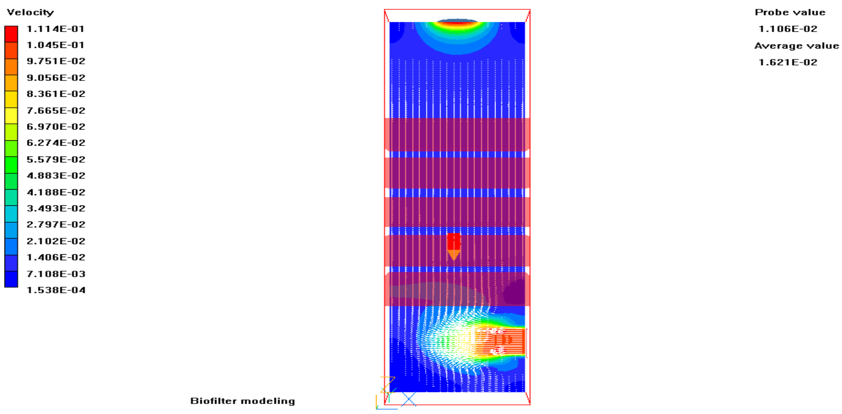

Fig. 7. Biofilter model setup using PHOENICS 3.5.1

As we can see from Figure 7, the turbulent air stream from the inlet creates uneven air flow through the first layers of biomedia in biofilter. This uneven air flow (Fig. 8) results the lower efficiency in toluene removal due to the fact, that the injected pollutant is not distributed evenly in the biomedia.

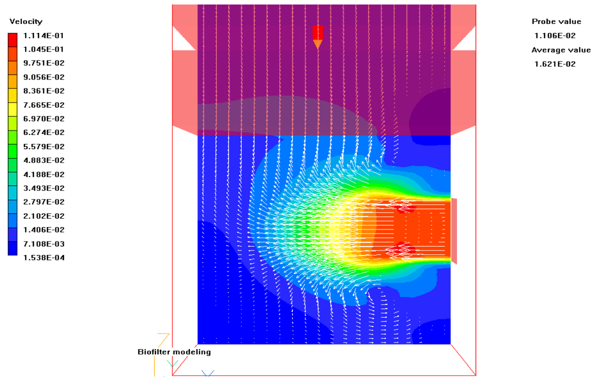

Fig. 8. Turbulent air low in biofilter lower section

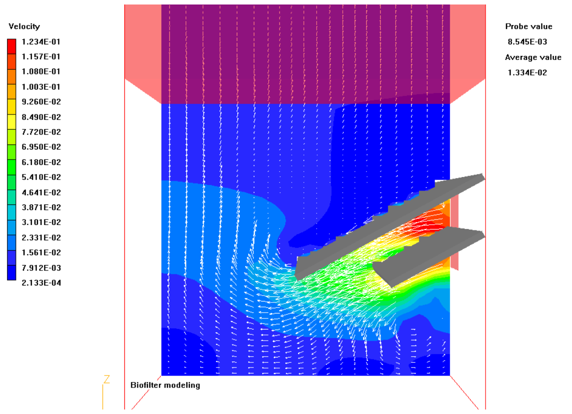

Fig. 9. Air flow in biofilter after the implementation of air stream directing plates

As we can see from Figure 9, the velocities near the first biomedia layer have decreased. This is because the air stream is being slowed when it encounters the designed plates and biofilter walls it its path. If we compare the velocities in the center of the first biomedia layer before and after the implementation of the pointing plates, we can see that their values have decreased by almost 50%.

5. Conclusions

1. It was determined that the biofilter performed best at removing the toluene from the polluted air stream when initial concentration ranged from 4 to 20 mg/m^3 (E = 92.0%), when the air stream flow rate was 0.02 m/s and the mixture of 70% coniferous and 30% deciduous wood waste charge of 10–20 mm fraction was used.

2. Analysis of biofilter performance, when pH value was kept at neutral (pH = 7), showed that the efficiency of biofilter depends on biomedia layer number and their height. Higher number of layers and height influence better efficiency of contaminated air treatment, e.g. toluene removal efficiency at initial concentration C = 22 mg/m^3 through one layer of 15 cm was equal to E = 71.5%, while passed through 5 layers of 75 cm height, the efficiency reached 89.2%. These results resemble 10–20 mm fraction wood waste mixture of 70% coniferous and 30% deciduous wood charge, which has porosity value of P = 46%.

3. The turbulent air stream is the cause of lower biofilter performance and thus lower effectiveness in toluene removal from the polluted air stream. Modeling results of biofilter air stream have shown that using directional plates can even the distribution of the air stream to biomedia by decreasing the turbulence and the velocities of the inlet air stream by almost 50%. This will increase the contact time of a pollutant in biofilm formed on biomedia which should increase the overall performance of the biofilter itself.

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