

Using Biofilter Packed with Different Wood Waste Charges for Purification of Air Contaminated with Benzene

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Abstract. The main aim of this work was the analysis and assessment of benzene removal from air using bio-filter packed with a mixture of wood waste. The results of this work show that the small scale bio-filter with various coniferous and deciduous wood waste charges is capable of efficiently removing benzene from polluted air stream. The analysis of different mixtures of wood waste charge, while pH value was kept at neutral (pH = 7), determined, that the best wood waste mixture is consisted of 70% coniferous wood (45% pine trees, 25% fir trees), 30% deciduous wood (20% maple, 10% hazel) which was consisted of 10–20 mm fraction particles and had porosity value of 46%. This bio-media was best used for benzene removal from contaminated air stream ($E = 93.86\text{--}74.78\%$).

Keywords: volatile organic compounds, biofilter, benzene, wood waste charge.

Introduction

Biofiltration is an extension of natural purification processes (Janni et al., 2001). Biofiltration is a process that uses microorganisms (degraders) to oxidize volatile organic compounds (VOCs) and oxidizable inorganic vapors and gases in an air stream. It is effective and economical for low concentrations of contaminant in large quantities of air. The contaminants are sorbed from gas to an aqueous phase where 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 (Deshusses & Cox, 2003). 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 (Deviny, 1999).

Microorganisms that are fixed to a porous medium to break down pollutants present in the air stream are used in biofiltration process. 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 (Deviny, 1999; Mohseni & Allen, 1998).

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 (Deviny & Ramesh, 2005). 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 ammonia are also biodegradable well (Deviny, 1999). 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 (Colón et al., 2009; Torkian et al., 2003).

The aim of this work will be the analysis and assessment of benzene removal from air using biofilter packed with a mixture of wood waste.

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1. Methodology

The biofilter used to carry out the experiment was developed at the Department of Environmental Protection and Water Engineering of Vilnius Gediminas technical University (Vaiškūnaitė, 2004).

Air purification 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 m³/h) and flow velocity (0.01 to 0.1 m/s). The temperature is maintained at 30 °C 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 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 m³). When the filter isn't operated, activity of microorganisms in the charge decreases, and water consumption goes down to 10 l (Vaiškūnaitė, 2004).

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); Fe₂(SO₄)₃ (0.1 g); KH₂PO₄ (1 g); NaNO₃ (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 (Vaiškūnaitė, 2004).

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 ir 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 (Zagorskis, 2009).

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

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.

2. Results and analysis

The removal efficiency of benzene in biofilter packed with first mixture of wood waste charge (70% coniferous wood, 30% deciduous wood) is shown in Figures 1 and 2. As mentioned before the pH value was kept approximately at neutral levels.

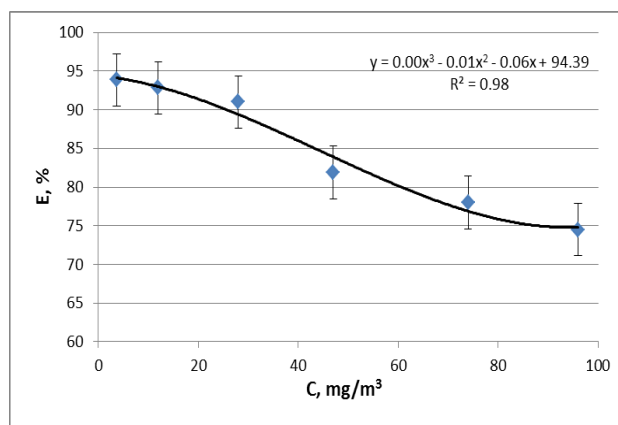


Figure 1. Overall removal efficiency of benzene (fraction size 10–20 mm, P = 46%)

Figures 2 and 3 shows the overall removal efficiency of benzene for air stream when using bio-filter packed with 10–20 mm and 20–50 mm fraction wood waste charge composed of 70% coniferous wood, 30% deciduous wood. All concentrations were measured three times and were estimated an average, which was used in graphics. As we can see from this figure, the bio-filter is effective at treating air stream from low concentrations of benzene. The removal efficiency up to 82.98% was determine when treating the polluted air stream up to 20 mg/m³ using 20–50 mm fraction wood waste charge. When using smaller fraction bio-media the effectiveness rises to 92.45% The deterioration in

effectiveness of benzene removal can be a result of benzene being more complex pollutant to biodegrade for microorganisms. Also, benzene has a cancerogenic and mutagenic effect on human health and living organisms and literature sources suggest that it has lower biodegradability value than formaldehyde and toluene (see Table 1). Also the benzene has a higher molar mass which is almost twice the molar mass of formaldehyde, but is less soluble in water and belongs to aromatic hydrocarbons which have stronger molecular bonds and therefore are more difficult to biodegrade.

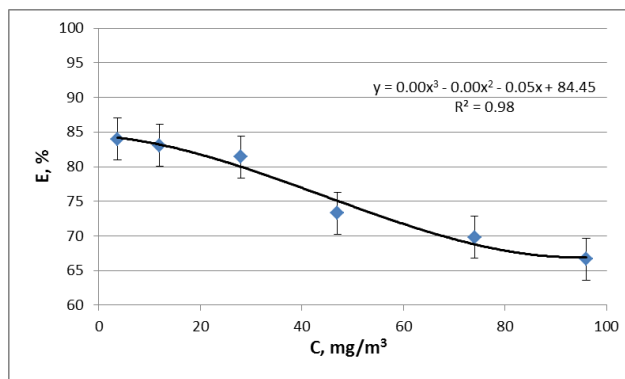


Figure 2. Overall removal efficiency of benzene (fraction size 20–50 mm, P = 67%)

Table 1. Characteristics of measured volatile organic compounds (Deshusses & Cox, 2006)

| Name | Chemical formula | Molar mass, g/mol | Solubility, g/l |
|--------------|-------------------------------|-------------------|-----------------|
| Formaldehyde | CH ₂ O | 30.03 | 400 |
| Toluene | C ₇ H ₈ | 92.12 | 0.47 |
| Benzene | C ₆ H ₆ | 78.11 | 0.8 |

The filter efficiency was tested depending on the number of its charge layers. The increase in the number of the layers from one to five resulted in higher efficiency of air cleaning due to greater amount of the biocharge 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 benzene removal efficiency depending on the layer height are given in Figure 3 and Figure 4.

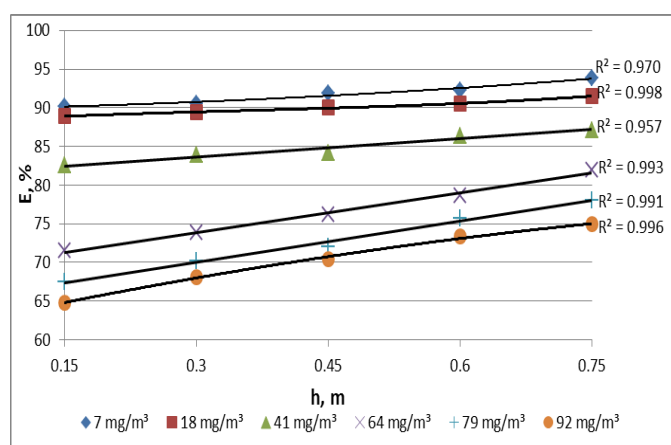


Figure 3. Removal efficiency of benzene (fraction size 10–20 mm, P = 46%)

As we can see from Figures 4 and 5 injecting the air with lower concentration (from 7 mg/m³ to 41 mg/m³) the air cleaning efficiency after one layer and after five layers hardly differed (4–17%). For example, the efficiency of air cleaning of benzene with the initial concentration of 7 mg/m³ after one charge layer (fraction size 10–20 mm) was 88.3% after five layers it was 93.6%. With the increasing initial pollutant concentrations, bio-filtration efficiency change after one and five layers reaches 5%. Moreover, the efficiency of air cleaning of benzene with the initial concentration of 41 mg/m³ after one charge layer (fraction size 20–50 mm) was 70.13%, after five layers it was 74.4%. With the increasing initial pollutant concentrations, bio-filtration efficiency change after one and five layers reaches

6%. The biggest change in efficiency is noticeable at higher values of initial concentration (e.g. starting from 64 mg/m³), but the overall removal efficiency at such concentrations is noticeably lower. In conclusion, the use of smaller fraction (10–20 mm) wood waste charge is more optimal due to the fact that it has a higher efficiency if compared to bigger fraction (20–50 mm) bio-media. The decrease in efficiency is caused by the change in porosity of the bio-media itself. The increase in fraction size brings higher porosity values and therefore, the contaminants that pass through the bio-filter charge layer absorb slower because the specific area on which the biofilm is formed is smaller.

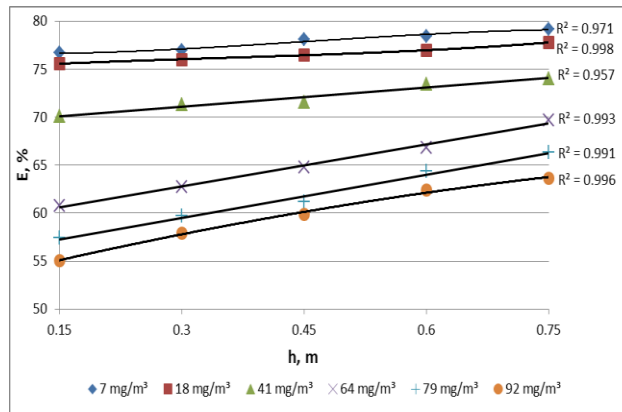


Figure 4. Removal efficiency of benzene (fraction size 20–50 mm, P = 67%)

Next experiment involved the determination of removal efficiency according to the air stream flow rate. During this experiment the air polluted with benzene was injected at the speed ranging from 0.02 to 0.1 m/s. The results of this experiment are shown in Figure 5 and Figure 6.

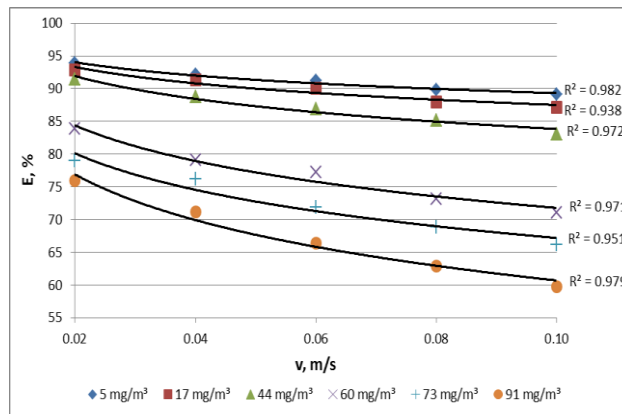


Figure 5. Benzene removal efficiency according to polluted air stream flow rate (fraction size 10–20 mm, P = 46%)

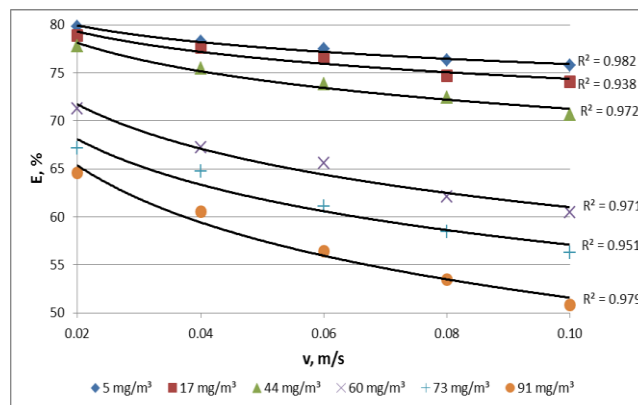


Figure 6. Benzene removal efficiency according to polluted air stream flow rate (fraction size 20–50 mm, P = 67%)

Figure 7 and Figure 8 shows the results when measuring the efficiency at the pH = 7. The bio-filter efficiency of 93.20% is achieved when the initial concentration of 5 mg/m³ and flow rate of 0.02 m/s, fraction size 10–20 mm were used. Accordingly, when the initial concentration of benzene is up to 17 mg/m³, the air to be clean may be injected at the speed of 0.06 m/s to achieve the efficiency of air cleaning higher than 90%. If the speed of the airflow passing the filter is increased to 0.1 m/s with the initial pollutant concentration 91 mg/m³, bio-filtration efficiency goes down to 59.2%.

When compare to the higher fraction (20–50 mm) wood waste charge, the efficiency drops to 50.83%, when the maximum initial concentration of 91 mg/m³ 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 overall removal efficiency of benzene in bio-filter packed with first mixture of wood waste charge (30% coniferous wood, 70% deciduous wood) is shown in Figures 8 and 9. As mentioned before the pH value was kept approximately at neutral levels.

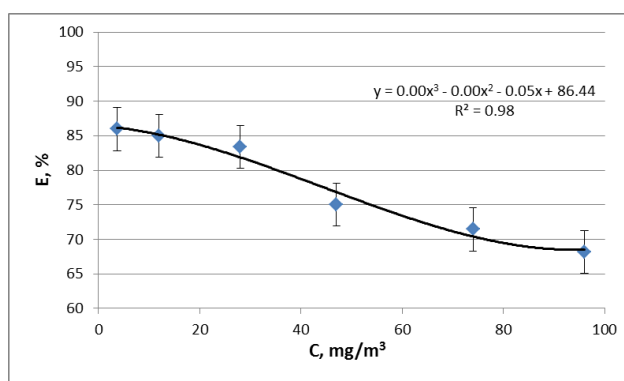


Figure 7. Overall removal efficiency of benzene (fraction size 10–20 mm, P = 51%)

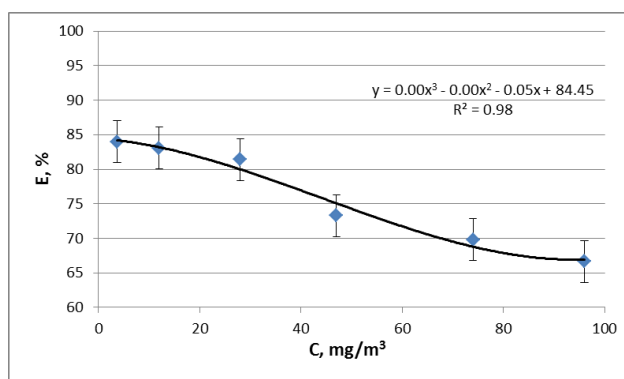


Figure 8. Overall removal efficiency of benzene (fraction size 20–50 mm, P = 72%)

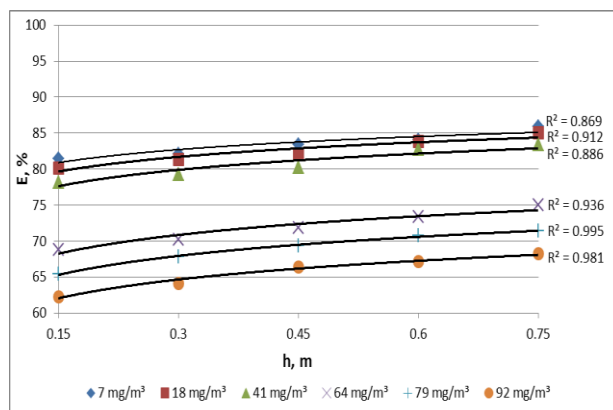


Figure 9. Removal efficiency of benzene (fraction size 10–20 mm, P = 51%)

Figures 8 and 9 shows the overall removal efficiency of benzene for air stream when using bio-filter packed with 10–20 mm and 20–50 mm fraction wood waste charge composed of 30% coniferous wood, 70% deciduous wood. The removal efficiency up to 85% was determine when treating the polluted air stream up to 15 mg/m³ using 10–20 mm fraction wood waste charge. When using higher fraction bio-media the effectiveness declined to 83%. The deterioration in effectiveness of benzene can be a result of benzene being more complex pollutant to biodegrade for microorganisms. Also the benzene has a higher molar mass which is almost twice the molar mass of formaldehyde, but is less soluble in water and belongs to aromatic hydrocarbons which have stronger molecular bonds and therefore are more difficult to biodegrade.

The filter efficiency was tested depending on the number of its charge layers. The increase in the number of the layers from one to five resulted in higher efficiency of air cleaning due to greater amount of the bio-media 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 benzene removal efficiency depending on the layer height are given in Figure 9 and Figure 10.

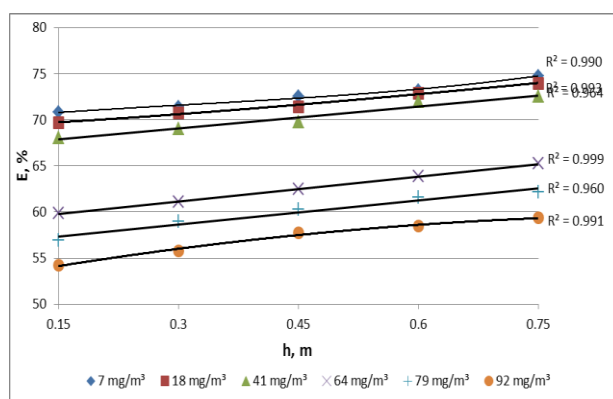


Figure 10. Removal efficiency of benzene (fraction size 20–50 mm, P = 72%)

As we can see from Figures 10 and 11, injecting the air with lower concentration (from 7 mg/m³ to 41 mg/m³), the air cleaning efficiency after one layer and after five layers differed by (4–11%). For example, the efficiency of air cleaning of benzene with the initial concentration of 7 mg/m³ after one charge layer (fraction size 10–20 mm) was 81% after five layers it was 96%. With the increasing initial pollutant concentrations, bio-filtration efficiency change after one and five layers reaches 5%. Moreover, the efficiency of air cleaning of benzene with the initial concentration of 7 mg/m³ after one charge layer (fraction size 20–50 mm) was 70%, after five layers it was 76%. With the increasing initial pollutant concentrations, bio-filtration efficiency change after one and five layers reaches 6%. The biggest change in efficiency is noticeable at higher values of initial concentration (e.g. starting from 64 mg/m³), but the overall removal efficiency at such concentrations is noticeably lower.

In conclusion, the use of smaller fraction (10–20 mm) wood waste charge is more optimal due to the fact that it has a higher efficiency if compared to bigger fraction (20–50 mm) bio-media. The decrease in efficiency is caused by the change in porosity of the bio-media itself.

Next experiment involved the determination of removal efficiency according to the air stream flow rate. During this experiment the air polluted with benzene was injected at the speed ranging from 0.02 to 0.1 m/s. The results of this experiment are shown in Figure 11 and Figure 12.

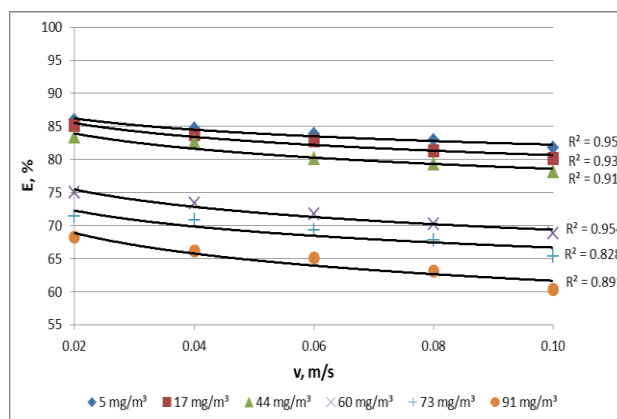


Figure 11. Benzene removal efficiency according to polluted air stream flow rate (fraction size 10–20 mm, P = 51%)

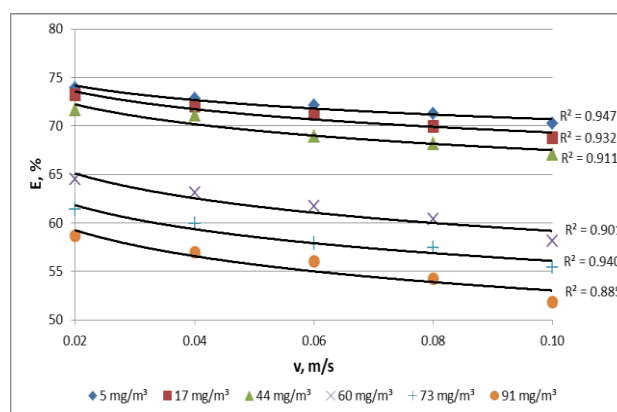


Figure 12. Benzene removal efficiency according to polluted air stream flow rate (fraction size 20–50 mm, P = 72%)

Figure 11 and Figure 12 shows the results when measuring the efficiency at the pH = 7. The bio-filter efficiency of 86% is achieved when the initial concentration of 5 mg/m³ and flow rate of 0.02 m/s, fraction size 10–20 mm were used. Accordingly, when the initial concentration of benzene is up to 17 mg/m³, the air to be clean may be injected at the speed of 0.08 m/s to achieve the efficiency of air cleaning higher than 70%. If the speed of the airflow passing the filter is increased to 0.1 m/s with the initial pollutant concentration 91 mg/m³, bio-filtration efficiency goes down to 60%.

When compare to the higher fraction (20–50 mm) wood waste charge, the efficiency drops to 52%, when the maximum initial concentration of 91 mg/m³ 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.

If we compare the given results with the first mixture of wood waste charge, we can see that the overall effectiveness of second bio-media is lower than the first wood waste charge, but the second charge containing deciduous wood waste charge is able to clean the contaminated air stream more effectively at higher initial concentration values (e.g. 91 mg/m³), when injecting the air stream at higher flow rate (0.1 m/s).

Conclusions

1. The results were acquired it was determined that the biofilter used in the experiment is best applicable benzene removal from contaminated air stream when when using biomedica composed of 70% coniferous and 30% deciduous wood waste.
2. After carefully studying the results it was determined that the biofilter performed best at removing the benzene from polluted air stream when initial concentration ranged from 4 to 20 mg/m³ (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.
3. The results of biofilter performance, when pH value was kept at neutral (pH = 7), showed that the efficiency of biofilter depends on biomedica layer number and their height. Higher number of layers and height influence better efficiency of contaminated air treatment e.g. benzene removal efficiency at initial concentration C = 22 mg/m³ 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%.

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