

EVALUATION OF THE PERFORMANCE WITH BIOFILTER EFFECTIVENESS TREATING VOLATILE ORGANIC COMPOUNDS UNDER DIFFERENT PH VALUE

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Abstract. The efficiency of a biofilter filled with pine bark charge was evaluated under conditions of interchanging pH. Hydrogen ion concentration is significance for the growth of microorganisms, therefore biological metabolism is strongly dependent on pH. Many micro-organisms will only grow within a particular pH range. However, it is necessary to know, which pH values suits the best for microorganisms growing, that degrades VOC in most intensive way and increase biological air treating efficiency. As a rough rule of thumb, most biological microorganisms growth occurs near a neutral pH (pH=7) and wide deviations from this will impair the efficiency of the biofilter.

Tests were performed with different pH regimes (4, 5, 6, 7, 8, 9 and 10) in pine bark charge. Depending on the maintained pH, spontaneous microorganism groups were cultivated in the biocharge. Moreover, the charge of pine bark generated a basic pH whereas a neutral pH is an optimum condition for bacterial growth. The results showed, that the obtained performance results revealed that the biofilter provided high removal efficiency E=98 % treating butanol which has a concentration C=5 mg/m³, butyl acetate (C=4 mg/m³, E=96 %), and xylene (E=81 %, C=7 mg/m³). Accordingly to the different pH value treating butanol environment conditions when pH=4, E=6.9 %; when pH=5 then E=49 %, when pH=6 then E=91.1 %, when pH=8 then E=91.1 %, when pH=9 then E=49 %, when pH=10 then E=8.6 %. Therefore, different environment condition (primary concentration, layer height of charge 0.15 – 0.75 m, air flow rate 0.02–0.1 m/s) were tested to ascertain dependence on pH value and biological air treatment efficiency.

Keywords: biofilter, biofiltration, volatile organic compounds, spontaneous microorganisms, biocharge pH.

1. Introduction

Every day thousands of tons of dangerous chemical pollutants such as volatile organic compounds (VOCs) are emitted to the environment and exert a negative effect on the ecosystems. Air pollutants released in one country may be transported in the atmosphere and harm human health and the environment elsewhere. According to the scientist Li, Vaiškūnaitė and Zigmontienė VOC are generally toxic gases emitted from wastewater treatment plants and many industries, such as printing and coating facilities, chemical industries, electronics, and paint manufacturing. In Lithuania, the average of VOC quantity released to the atmosphere from 2000 to 2010 was 23.3 thousand tones. Generally, in Lithuania the following hydrocarbons are found in the air at industrial concerns: benzene, toluene, xylene, isomers, etc., which could be removed with a help of biofilters (Baltrėnas *et al.* 2005).

Biofilter is a column filled with a porous packing material inoculated with microorganisms able to degrade pollutants. Biofilters can be designed with stacked beds to minimize space requirements and multiple units can be run in parallel. Furthermore, biofiltration is versatile

enough to treat odors, toxic compounds, and VOCs (Vaiškūnaitė and Miškinytė 2008). The efficiency of biological air treatment of these constituents are above 90 % for low concentrations of contaminants (<1000 ppm).

By the scientist J. Liang, packing material is a crucial component of a bioreactor as it is the microbial population's habitat. Traditional packing media have some problems such as compaction, acid degradation and frequent replacement. Use of a superior filter medium could overcome or minimize many of the problems encountered in conventional biofilter operation. According to the scientist Chan and Hwang, Baltrėnas Vaiškūnaitė and Zagorskis the optimal filter material should have the following characteristics: high moisture holding capacity, porosity, available nutrients, and pH buffer capacity. The packing materials commonly used in biofiltration are peat, compost, soil, straw, activated carbon granules, sludge from sewage treatment plants or pine bark (Baltrėnas and Zagorskis 2008).

In biofiltration process hydrogen ion concentration plays a significant role in the growth and the reproduction of microorganisms (Vaiškūnaitė 2008). Therefore, it should be considered to environmental pH, which influences the biological activity of microorganisms and

herewith influences the efficiency of biofilter treating volatile organic compounds.

Scientific articles and tasks about biological air treatment technologies were done by Vaiškūnaitė (2004), Zigmontienė (2004), Baltrėnas (2004), Zagorskis (2009), the science doctors of Vilnius Gediminas Technical university. Ecologic Institut science doctor Balevičius (2002) was analysed about biofiltration technologies with macrofitas investigation on pH. In addition, a man of science Mongirdas and Kusta (2005) researched biofiltration process.

Additionally, scientific articles and worksheets related with biological air purification were published by biotechnology and bioengineering scientists Aizpuru, Malhautier, Khammar, Gunsch. There are a huge scientists from China universities which are interested in biofiltration process of different charge pH such as Lu, Chang, Quan, Li, Wang. Moreover scientists from Nanyang technological university (Singapore) Liang, Chiaw, Ning were published scientific articles about the influence of hydrogen ion concentration to the efficiency of biological air treatment.

The aim of the experimental researches is to evaluate the efficiency of the biofilter by varying biocharge pH regimes (4, 5, 6, 7, 8, 9 and 10), filter parameters (charge height and air flow speed), and initial concentrations (up to 100 mg/m³) of the following pollutants: butanol, butyl acetate and xylene.

2. Investigation methods

Biofilter with a pine bark charge was used for the experimental tests in Vilnius Gediminas technical university, department of Environmental Protection. The biofilter (0.5x0.48x2.0 m) with biologically activated charge contains five separate layers of biomedium, which don't press each other, are separated mesies and ensure even distribution of airflow. The experimental device contained five separate 0.15 m high layers instead of containing a single 0.75 m high layer. Treating the polluted air with volatile organic compounds, the flow of polluted air passes through all five layers of biomass. Valves installed in the air duct regulate the speed of the incoming and outgoing airflow passing through the filter (from 0.02 to 0.1 m/s). To enhance the speed of the polluted air, the entrance and duct is of a cowl form. The cleaned air is exhausted from the filter through the flexible exit air duct (Baltrėnas and Vaiškūnaitė 2003).

Different pH regimes were used in the pine bark charge: 4, 5, 6, 7, 8, 9 and 10. The necessary pH was achieved by temperature, moisture content and calcium oxide. Higher temperature 45 °C and lower moisture content 20–30 % influence acidic pH. Moreover, biodegradation of volatile organic compounds decline pH to acidic medium too. To enhance pH value it was chosen calcium oxide (CaO). 4 g CaO is necessary to increase the value of pH 2.8. For instance, if pH=7 it is added 4 g CaO and then the pH value is 9.8. The filter contained a pH measurement opening, to take pH value with pH-meter 538 device.

The biological air treatment process could be started after microorganisms activation, which continues about two weeks. In activation process, volatile organic compounds are heated and evaporised. When air cleaning process was in progress, 20

l of water per day was used to maintain humidity of 60 % in the whole volume of the bark (0.18 m³). With the help of five pumps water from a reservoir was pumped to each layer so that 60 % moisture content was maintained. Water was spread above each layer and its excess was collected in the waste collector together with waste generated. Charge humidity was monitored periodically by weighting method, by desiccating bark samples at 100–105 °C until constant weight was obtained. The necessary temperature 28 °C in the filter was achieved by heating bio-medium at the side walls of the filter with the help of two heating elements.

For microbial growth there are three essential elements: carbon (C), nitrogen (N), and phosphorus (P). Carbon can be provided by the VOCs in the air stream, but both nitrogen and phosphorus must be provided by the filter material according to the scientists Vanloon and Duffy. Prior to starting the equipment and when operating it, up to 0.43 kg of solution of mineral salts (K₂HPO₄ – 1 g, KCl – 0.5 g, FeSO₄ · 7 H₂O – 0.1 g, NaNO₃ – 0.91 g, MgSO₄ · 7 H₂O – 0.5 g per week were consumed. These mineral salts are necessary to obtain energy and growth of microorganisms. Biogenic elements were consumed by microflora in the charge together with sprinkled water. It was used speed meter „TESTO-452“ with thermopair to measure the air flow rate in this experimental researches. When increasing speed of the airflow injected up to 0.1 m/s, measurement error also increased. Each measurement was repeated five times. To assess the aerodynamic resistance of charge differential pressure device „DSM-1“ was used. It was performed 5 measurements in every layer of biomedium and the averages of obtained result were derivable.

In experimental researches were applied different composition of volatile organic compounds (butanol, butyl acetate and xylene), their initial concentrations, airflow speed, and the height of charge layers. To compare volatile organic compounds biodegradation in the activated pine bark charge, six different concentrations up to 100 mg/m³ were taken approximately every 15–20 mg/m³.

Concentration of pollutants was determined by photo-ionization sensor MiniRAE 2000, which has 9.8, 10.6, or 11.7 eV UV lamp. MiniRAE 2000 consists of a PID with associated microcomputer and electronic circuit. The unit is housed in a rugged ABS + PC case with a backlit 1 line by 8 character dot matrix LCD and 3 keys to provide easy user interface. Device MiniRAE 2000 is built to measure 102 VOC gases. Temperature range of this photo-ionization sensor is from 0 to 45°C (32 to 113°F), and relative humidity range is from 0 to 95 %.

After determining concentrations of volatile organic compounds under investigation by MiniRAE 2000 analysis, efficiency of biofilter was estimated. Furthermore, during the experiment the temperature of laboratory was 18–20 °C, atmospheric pressure 749–751 mm Hg column and humidity 68 % (Baltrėnas and Vaiškūnaitė 2003).

3. Investigation results

The performed experimental tests revealed that filter efficiency depended on the hydrogen ions concentration maintained in the charge. During the experimental testing,

different initial concentrations (up to 100 mg/m^3) of volatile organic compounds (butanol, butyl acetate and xylene) were injected into the biofilter at different pH regimes (4, 5, 6, 7, 8, 9 and 10) and different main parameters of the filter (charge height and airflow speed). Under different pH regimes, hydrogen ions concentration was measured at different layers of the charge and different depths of the layers. First of all, tests were performed in the filter charge with neutral medium $\text{pH}=7$. Then tests were performed with the charge, where it was acidic medium $\text{pH}<7$ and final analysis were done with a charge, where it was alkaline medium $\text{pH}>7$. Depending on the maintained pH, spontaneous microorganism groups were cultivated in the charge. Science researcher Gaudin knows, that every material generated a basic pH whereas a neutral pH is an optimum condition for bacterial growth.

Biological metabolism is strongly dependent on pH. Many microorganisms will only grow within a particular pH range. As a rough rule of thumb, most biological growth occurs near a neutral pH and wide deviations from this will impair the efficiency of the biofilter (Mcnevin and Barford 2000a). In the work of the scientist Aizpuru, it was determined, that the biodegradation is very significantly increased when the waste was saturated with water and the pH adjusted above 6.5. By the scientists Akao and Tsuno the activities of the microorganisms inside the biofilter will decrease if pH value is too low. Therefore, the culture medium should be neutralized to increase the rate of biodegradation and to minimize the residence time of the organic pollutants in a treatment unit (Nievas *et al.* 2005).

Air treatment efficiency reaches 100 %, when pH value is 7, the efficiency of biological air treatment is 50 % when pH is 5 and 9. Moreover, the efficiency of air treatment decreases, when pH grows or diminishes (Fig. 1). This example is very general, cause air treatment efficiency depends not just on pH value, but depends on temperature, moisture content, air flow rate, concentrations of VOC and etc.

At the first, it was done an experiment with different concentration of butanol. Injecting the air with lower concentration from $5\text{--}15 \text{ mg/m}^3$ to major concentration of butanol $78\text{--}98 \text{ mg/m}^3$ depending on the pH value.

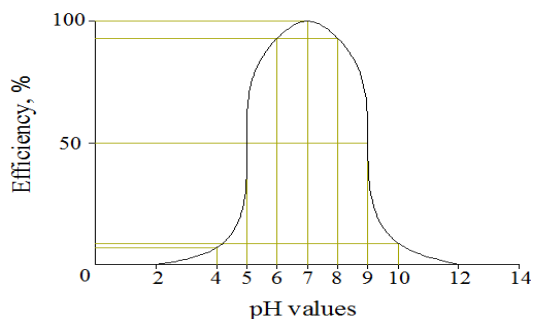


Fig 1. The relationship between pH and efficiency

The increase $\text{pH}>7$ and decrease $\text{pH}<7$ resulted in less efficiency of air cleaning due to greater amount of the biocharge and higher concentration spontaneous microorganisms. From the Fig. 2 it can be seen, that the greatest efficiency treating butanol is reached, when pH is 7

with all concentrations, for example, when the concentration is 5 mg/m^3 than efficiency of biological air treatment is 98 %, $15 \text{ mg/m}^3 - 95 \%$, $31 \text{ mg/m}^3 - 91 \%$, $52 \text{ mg/m}^3 - 89 \%$, $78 \text{ mg/m}^3 - 83 \%$, $98 \text{ mg/m}^3 - 78 \%$. When pH decreases then efficiency of treatment falls too. For instance, if it is taken 31 mg/m^3 the efficiency is 6.4% when $\text{pH}=4$, 45.5 % when $\text{pH}=5$ and 84.6% when $\text{pH}=6$. Moreover, efficiency falls also when pH is grows, for example, efficiency is 84.6 % when $\text{pH}=8$, 45.5 % when $\text{pH}=9$ and 8 % when $\text{pH}=10$. To take a note, that efficiency of the biofilter treating air polluted with butanol has similar values, for instance: $\text{pH}=6$ and $\text{pH}=8$ influence the efficiency of treatment likewise 84.6 %.

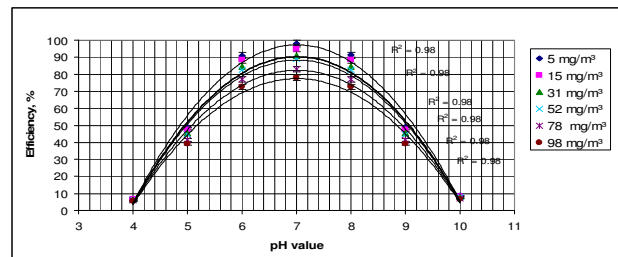


Fig 2. The relationship between efficiency and pH, treating different butanol concentrations, when air flow rate is 0.1 m/s

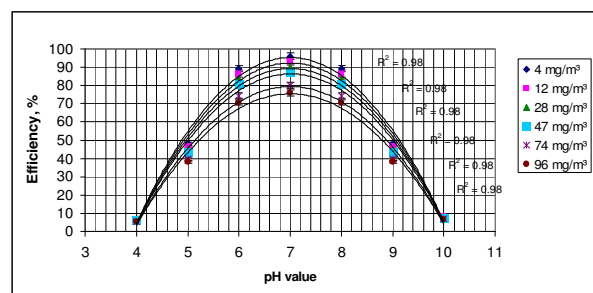


Fig 3. The relationship between efficiency and pH, treating butyl acetate of different concentrations, when air flow rate is 0.1 m/s

The filter efficiency treating butyl acetate was tested depending on the pH value too. The greatest efficiency treating butyl acetate from air flow was reached, when pH was 7 with 4 mg/m^3 concentration of pollutant (Fig. 3). When pH decreases then efficiency of treatment falls. For instance, if it is taken 47 mg/m^3 the efficiency is 6.1% when $\text{pH}=4$, 43.5 % when $\text{pH}=5$ and 80.9 % when $\text{pH}=6$. Moreover, efficiency reduces also when pH increases, for example, efficiency is 80.9 % when $\text{pH}=8$, 43.5 % when $\text{pH}=9$ and 7.7 % when $\text{pH}=10$.

Less water soluble and slowly biodegrading compound pollutant, xylene, was injected through the biofilter at different pH (4, 5, 6, 7, 8, 9 and 10) values regime in the filter. Comparing with the above described results of pollutant tests (butanol and butyl acetate), the biofiltration efficiency of xylene removal of the air varied within 53–81%, when $\text{pH}=7$. With the initial concentrations of xylene amounting to 63 mg/m^3 , the air cleaning efficiency when $\text{pH}=4$ is just 4.6 %, with $\text{pH}=5$ the efficiency increased till 32.5 %, moreover when $\text{pH}=6$ the efficiency is 60.45 % (Fig. 4).

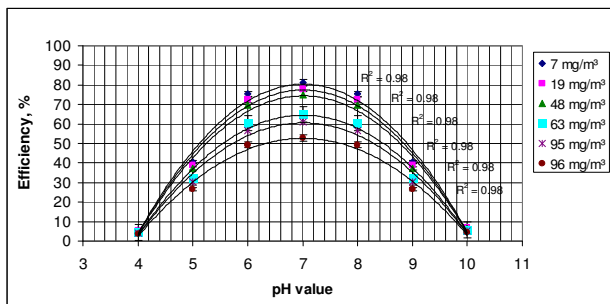


Fig 4. The relationship between efficiency and pH, treating xylene of different concentrations, when air flow rate is 0.1 m/s

Hydrogen ions concentrations variation in the charge depends on the following: a microorganism group cultivated in it, also nutrient necessary for the growth of microorganisms, a temperature of the polluted airflow, a moisture content.

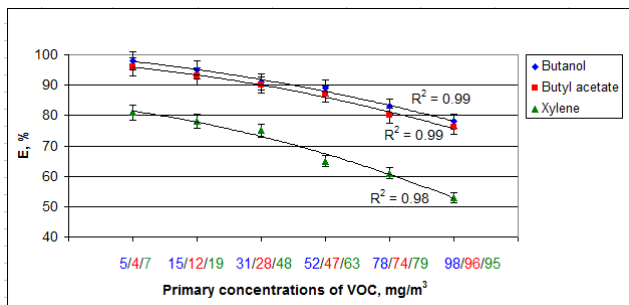


Fig 5. The relationship between efficiency and primary concentrations of butanol, butyl acetate and xylene, when air flow rate is 0.1 m/s and pH=7

The Fig. 5 shows the relation between air treatment efficiency and concentrations of volatile organic compounds, when pH=7. It can be seen, that the greatest efficiency is treating butanol with various concentrations, for example when the concentration of butanol is 5 mg/m³ the efficiency is 98 %, 15 mg/m³ – 96 %, 31 mg/m³ – 91 %, 52 mg/m³ – 89 %, 79 mg/m³ – 83 %, 98 mg/m³ – 78 %. The variation of efficiency treating butanol at different concentration is from 98 % till 78 %. Treatment of butyl acetate from waste air flow is less efficient comparing with butanol. The variation of efficiency treating butyl acetate from waste air flow at different concentration is from 96% till 76%. Sharp difference is between xylene and butanol/butyl acetate. When it is taken similar concentrations of pollutants for instance range 4–7mg/m³, the efficiency varied from 98–96 % (treating butanol and butyl acetate) and 81 % treating xylene.

The efficiency of biofilter is very low, when pH=4, it varied just in 3.7–6.9% range. The highest efficiency treating butanol is 6.9 %, butyl acetate 6.7 % and treating xylene 5.7 %. The lowest efficiency is 5.5 % when treating butanol, 5.3 % treating butyl acetate and 3.7 % treating xylene (Fig. 6).

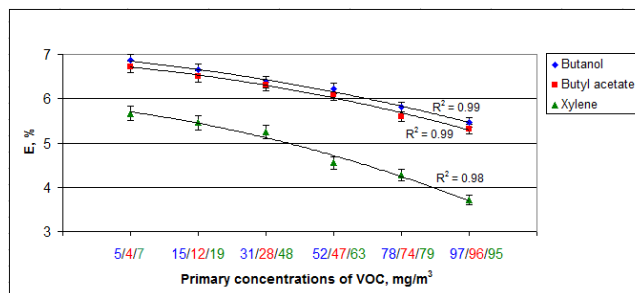


Fig 6. The relationship between efficiency and primary concentrations of butanol, butyl acetate and xylene, when air flow rate is 0.1 m/s and pH=4

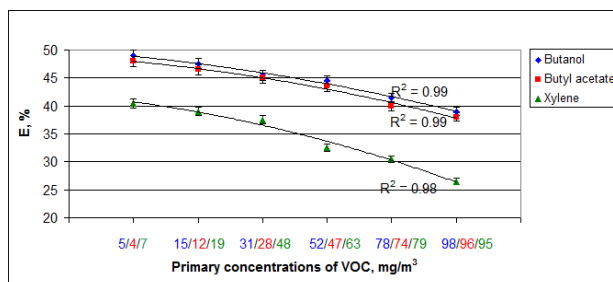


Fig 7. The relationship between efficiency and primary concentrations of butanol, butyl acetate and xylene, when air flow rate is 0.1 m/s and pH=5

Further analyses show the results at pH=5. From the Fig. 7 it can be seen, that the efficiency decreases when the concentrations of pollutants increases. The efficiency treating butanol and butyl acetate at similar concentration is going resemblance, for example 5 mg/m³ of butanol gives 49 % efficiency, while 4 mg/m³ of butyl acetate gives 48 %, the difference between treating butanol and butyl acetate is 1%. Moreover, 98 mg/m³ of butanol gives 39 % efficiency, while 96 mg/m³ of butyl acetate gives 38 %, the difference between treating butanol and butyl acetate is 1 % also. With the pH=5 in the filter charge, xylene was to a lesser extent degraded by microorganisms. When the initial concentrations of this pollutant were 7–95 mg/m³, the filter was functioning at the efficiency of 40.5–26.5 %.

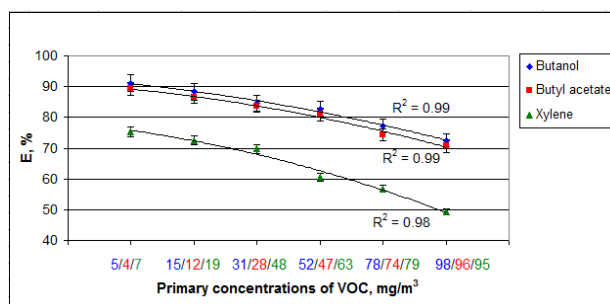


Fig 8. The relationship between efficiency and primary concentrations of butanol, butyl acetate and xylene, when air flow rate is 0.1 m/s and pH=6

The Fig. 8 shows the relation between air treatment efficiency and concentrations of volatile organic compounds, when pH=6. It can be seen, that the greatest efficiency is treating butanol with various concentrations

and it is varied between 72.5 and 91.1%. The lowest efficiency is treating xylene, the variation range of efficiency is from 49.3 till 75.3 %.

The usage of a biofilter packed with crab shells could be an example, how to increase pH value. For instance, the addition of 0.5–5 g of crab shells into 100 ml of distilled water increased the pH value from 6.5 to 9.5 ~ 10.5 and the crab shells are believed to prevent acidification of biofilter (Kwon and Yeom 2009). In the experiment it is needed to ascertain suitable value of pH, cause pH is very important factor which determines the intensity of microorganisms growth, further the efficiency of biological air treatment. Therefore it was chosen calcium oxide (CaO) to enhance the value of pH in my experimental researches. To take a note, that 4 g CaO is necessary to increase the value of pH 2.8. For example, if pH=7 it is added 4 g CaO and then the pH value is 9.8.

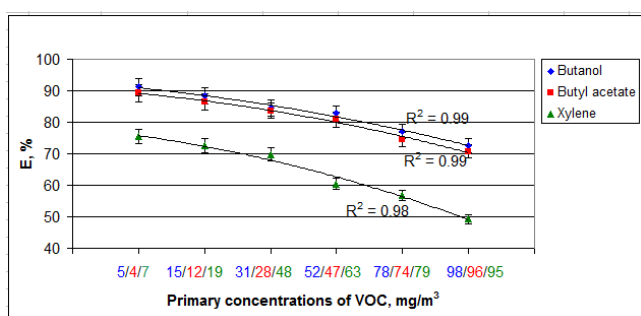


Fig 9. The relationship between efficiency and primary concentrations of butanol, butyl acetate and xylene, when air flow rate is 0.1 m/s and pH=8

From the Fig. 9 it can be seen, that the greatest efficiency is treating butanol with various concentrations, for example when the concentration of butanol is 5 mg/m³ the efficiency is 91.1 %, 15 mg/m³ – 88.4 %, 31 mg/m³ – 84.6 %, 52 mg/m³ – 82.8 %, 79 mg/m³ – 77.2 %, 98 mg/m³ – 72.5 %. Treatment of butyl acetate from waste air flow is less efficient comparing with butanol, the difference at similar concentrations is about 2%. Strong difference is between the efficiency of xylene and butanol/butyl acetate, it varies in 15–23 % range.

Biological air treatment efficiency decreases when the concentrations of pollutants increases. The efficiency treating butanol and butyl acetate at similar concentration is going resemblance, for example 15 mg/m³ of butanol gives 47.5 % efficiency, while 12 mg/m³ of butyl acetate gives 46.5 %, the difference between treating butanol and butyl acetate is 1 %. Moreover, 78 mg/m³ of butanol gives 41.5 % efficiency, while 74 mg/m³ of butyl acetate gives 40 %, the difference between treating butanol and butyl acetate is 1.5 %. With the pH=9 in the filter charge, xylene wasn't degradable as well as butanol and butyl acetate. When the initial concentrations of this pollutant were 19–79 mg/m³, the filter was functioning at the efficiency of 39–30.5 % (Fig. 10).

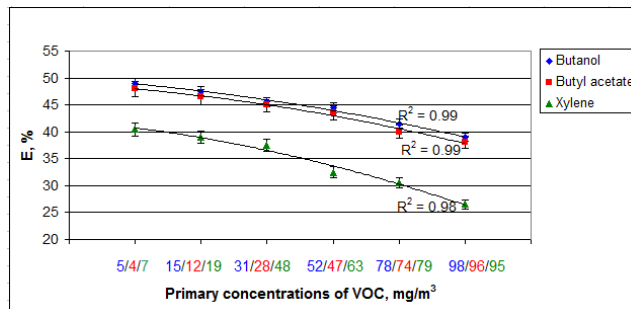


Fig 10. The relationship between efficiency and primary concentrations of butanol, butyl acetate and xylene, when air flow rate is 0.1 m/s and pH=9

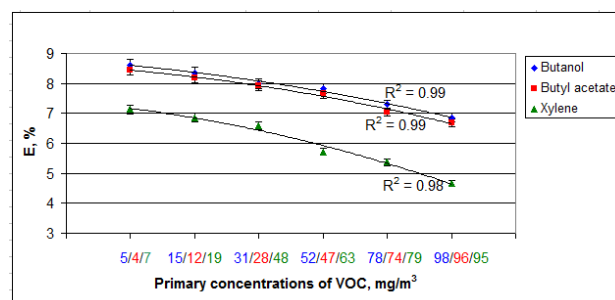


Fig 11. The relationship between efficiency and primary concentrations of butanol, butyl acetate and xylene, when air flow rate is 0.1 m/s and pH=10

The efficiency of biofilter is very low, when pH=10, it varied just in 4.7–8.6% range. The highest efficiency purifying butanol is 8.6 %, treating butyl acetate 8.5 % and treating xylene 7.1 %. The lowest efficiency is 6.9 % when purifying butanol, 6.69% treating butyl acetate and 4.7 % treating xylene (Fig. 11).

It is analysed the relation between air treatment efficiency and primary concentrations of volatile organic compounds such as butanol, butyl acetate and xylene at different pH values (4, 5, 6, 7, 8, 9 and 10).

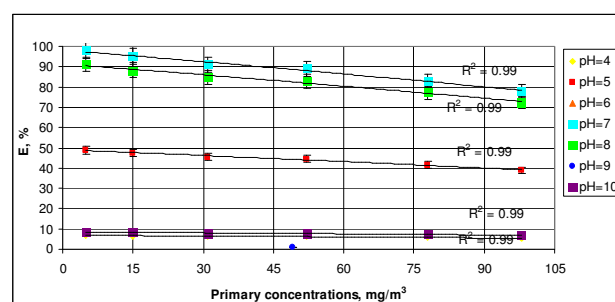


Fig 12. Efficiency of biofilter treating different butanol concentrations at pH 4, 5, 6, 7, 8, 9 and 10

The Fig. 12 shows the relationship between efficiency and different butanol concentrations at particular pH values. The optimal biofilter efficiency reaches, when pH=7 and the efficiency varied between 98–78% with 5 mg/m³ and 98 mg/m³ concentrations. Great efficiency is reached when pH=6 and pH=8, then efficiency varies from 91.1–72.5 %. Furthermore, when pH has the value of 5 or 9, the efficiency decreases and

fluctuates between 49 and 39 %. The lowest similar efficiency of air treatment varies from 8.6 till 5.5 %, when pH=4 or pH=10. To take a note, the efficiency treating different butanol concentrations is greater at pH=10, than at pH=4 and the difference is 1.4–1.8 %.

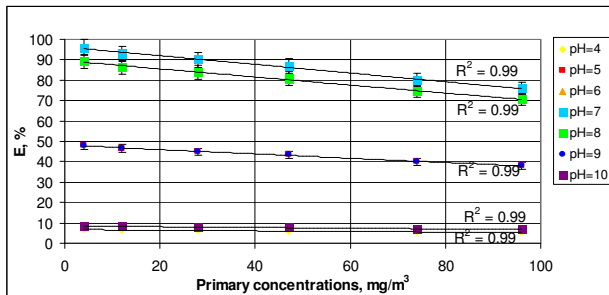


Fig 13. Efficiency of biofilter treating different butyl acetate concentrations at pH 4, 5, 6, 7, 8, 9 and 10

The efficiency of air treatment treating butyl acetate decreases when the concentrations of pollutants increases. Just efficiency varies very little when pH is 4 and pH=10, for instance: the difference between efficiency is 1.4 at pH=4 and the efficiency is 1.7% at pH=10. The greatest treatment efficiency is reached, when pH=7 (Fig. 13).

The Fig. 14 shows the relation between efficiency and different xylene concentrations at particular pH values. The optimal biofilter efficiency reaches, when pH=7 and the efficiency varied between 81–53 % with 7 mg/m³ and 95 mg/m³ concentrations. Great efficiency is reached when pH=6 and pH=8, then efficiency varies from 75.3–49.3 %. Furthermore, when pH has the value of 5 or 9, the efficiency decreases and fluctuates between 40.5 and 26.5%. The lowest similar efficiency of air treatment varies from 7.1 till 3.7%, when pH=4 or pH=10.

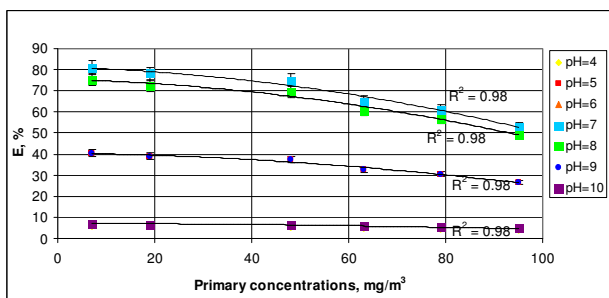


Fig 14. Efficiency of biofilter treating different xylene concentrations at pH 4, 5, 6, 7, 8, 9 and 10

In the experiment, the filter efficiency was tested depending on the number of its charge layers (i.e. number of its 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 spontaneous chemoorganotrops. When the number of layers was increased up to five, efficiency of air cleaning at that same initial concentration was higher. For example, with the initial concentrations of pollutants (butanol and butyl acetate) amounting to 98–96 mg/m³ and the charge pH=7, the air cleaning efficiency after the air passed one layer was 61–57

%, and after passing five layers it increased by 17–19 % and reached (78–76 %) (Figs. 15–16).

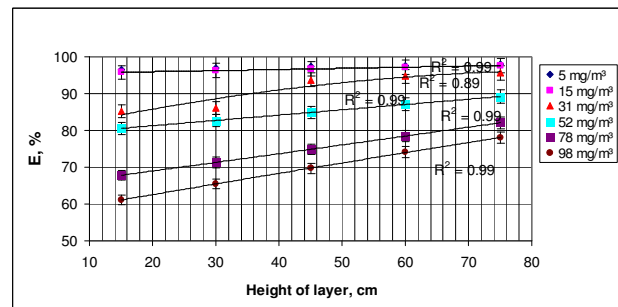


Fig 15. Efficiency of air cleaning from butanol depending on the number of layers, when speed of the airflow injected was 0.1 m/s and pH=7

Injecting the air with lower concentration (from 4–7 to 28–48 mg/m³), the air cleaning efficiency after one layer and after five layers hardly differed (5–11%) For example, the efficiency of air cleaning of butanol with the initial concentration of 31 mg/m³ after one charge layer was 85 %, after five layers it was 96 %. With the increasing initial pollutant concentrations, biofiltration efficiency change after one and five layers reaches 11 %. Moreover, the efficiency of air cleaning of butyl acetate with the initial concentration of 28 mg/m³ after one charge layer was 90 %, after five layers it was 95%. With the increasing initial pollutant concentrations, biofiltration efficiency change after one and five layers reaches 5%.

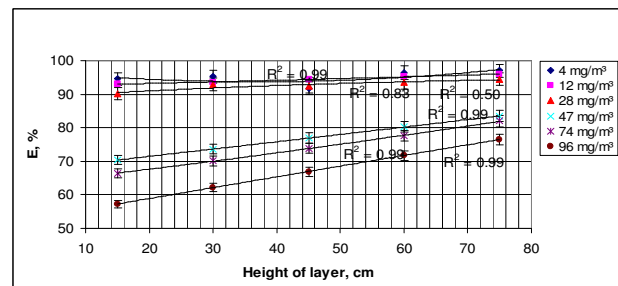


Fig 16. Efficiency of air cleaning from butyl acetate depending on the number of layers, when speed of the airflow injected was 0.1 m/s and pH=7

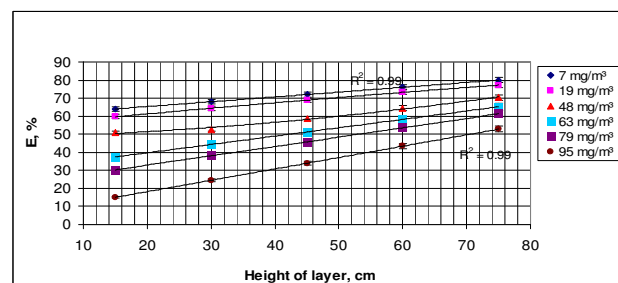


Fig 17. Efficiency of air cleaning from xylene depending on the number of layers, when speed of the airflow injected was 0.1 m/s and pH=7

With the increased initial concentrations of the above mentioned pollutants, difference in biofiltration efficiency

after one and five charge layers is greater. For example, with the initial concentrations of pollutants (butyl acetate and xylene) amounting to 96–95 mg/m³ and the charge pH=7, the air cleaning efficiency after the air passed one layer was 15–57 %, and after passing five layers it increased by 20–38 % and reached (77–53 %) (Figs. 16–17).

Less water soluble and slowly biodegrading organic compound pollutant, xylene, was injected through the biofilter at pH=7 regime in the filter. Comparing with the above described results of pollutant tests (butanol and butyl acetate), the biofiltration efficiency of xylene removal of the air varied within 16–37 %. For example, with the initial concentrations of xylene amounting to 7–19 mg/m³, the air cleaning efficiency after the air passed one layer increased 16.5 % if compared to 64–60 %, and after passing five layers it reached 80–77 %. For example, when the initial xylene concentration was 48 mg/m³, the biofilter efficiency after one charge layer was 51 %, and respectively: 63 mg/m³ – 37 %, 79 mg/m³ – 30 %, 95 mg/m³ – only 15 %. On the grounds of these test results we could state that with the pH=7 regime in the biocharge and with the initial xylene concentrations exceeding 60 mg/m³, air cleaning efficiency after five biocharge layers will reach 52–65 %. During the tests a very insignificant change (on the average, about 30–34%) in the cleaning efficiency was recorded, which depended on the height if the biocharge layers. For example, when the initial xylene concentration was 63 mg/m³, the air cleaning efficiency after one charge layer was 37 %, after two – 44 %, after three – 51 %, after four – 58 %, after five – 65 %.

A number of tests carried out with pH regimes (4, 5, 6, 7, 8, 9 and 10) in the biocharge revealed that the filter efficiency depended not only on the number of charge layers but also on the speed of the air passing the filter.

All tests were carried out in pH=7 regime. During these tests, the air polluted with butanol, butyl acetate and xylene was injected at the speed of 0.02 to 0.1 m/s. Additionally, volatile organic pollutants biodegradation of which is easier (butanol and butyl acetate) were injected through the charge. At the pH=7 the filter efficiency of 96% is achieved when the speed of butanol with the initial concentration of 31 mg/m³ is 0.06 m/s. Accordingly, when the initial concentration of butanol is up to 52 mg/m³, 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 91 %. The highest efficiency of biofiltration is achieved (as high as 99.5 %) at the biocharge pH=7, when low concentrations (5 mg/m³) of the above mentioned pollutant pass the filter at the speed of 0.02 m/s. High biofiltration efficiency (up to 95 %) is reached after increasing the initial concentrations of the pollutant up to 96 mg/m³ and injecting the air through the filter at the speed of 0.02 m/s. If the speed of the airflow passing the filter is increased to 0.1 m/s without changing the above mentioned test conditions (the initial pollutant concentration 95 mg/m³, biofiltration efficiency goes down to 78 % (Fig. 18).

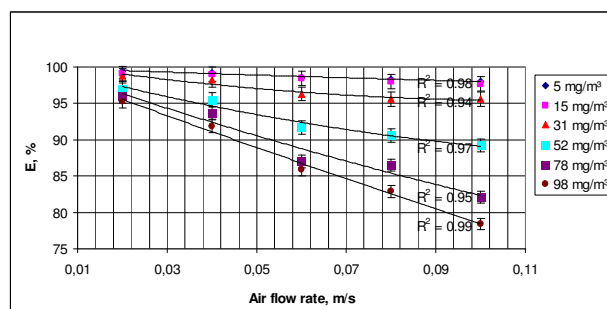


Fig 18. Efficiency of air cleaning from butanol depending on the speed of the airflow, when pH=7

Similar trends of experimental tests were recorded when cleaning the air of butyl acetate at the charge pH=7. For comparison, the efficiency of butyl acetate biofiltration was 0.5% lower than that of butanol. The highest efficiency (over 99%) of air cleaning was recorded when the initial concentrations of butyl acetate was 4 mg/m³ and passed the filter at speed 0.02 m/s. When the initial concentrations of butyl acetate reached 28 to 47 mg/m³, the biofiltration efficiency hardly changed at different airflow speed. For example, when the initial concentration of the above mentioned pollutant was 28 mg/m³ and the airflow speed was 0.02 m/s, the filter efficiency was 98.5%; respectively, at the speed of 0.04 m/s the filter efficiency was 97.6%, at 0.06 m/s it was 97.4%, at 0.08 m/s it was 95.1%, at 0.1 m/s it was 94.5%. Cleaning the air of butyl acetate, the lowest efficiency of biofiltration is achieved when the initial pollutant concentration is 96 mg/m³ and the speed is 0.1 m/s (Fig. 19).

Tests were also carried out on the air polluted with xylene by injecting the air through the filter maintaining pH=7 in the filter. When the initial xylene concentrations were up to 19 mg/m³, air cleaning efficiency was affected by the speed of the passing air, and the efficiency reach 88%, when the air flow rate was 0.02 m/s. Increasing the speed (up to 0.1 m/s) of the air passing the filter and mentioned concentrations of pollutants, the efficiency of biological air treatment process was 77 mg/m³. Moreover, with the initial pollutant concentration of 96 mg/m³ and its speed of 0.1 m/s, the air cleaning efficiency was only 52.8 %. Thus, to achieve more than 70 % efficiency of air cleaning of xylene, the initial concentrations of which are 95 mg/m³, the pollutant has to pass the filter at the speed not exceeding 0.02 m/s (Fig. 20).

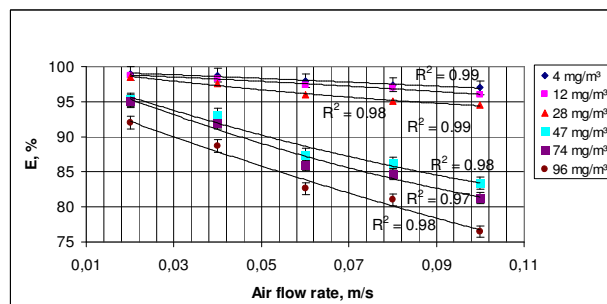


Fig 19. Efficiency of air cleaning from butyl acetate depending on the speed of the airflow, when pH=7

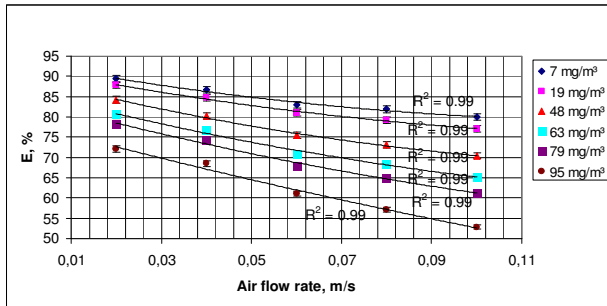


Fig 20. Efficiency of air cleaning from xylene depending on the speed of the airflow, when pH=7

The air polluted with xylene was injected at the speed of 0.02 to 0.1 m/s. Accordingly, when the air flow rate of xylene is up to 0.1 m/s, the efficiency of air treatment decreases. The highest efficiency of biofiltration treating different xylene concentrations is varied between 72.1 and 89.4 % at the speed of 0.02 m/s. While the lowest efficiency varied in 52.8–80 % at the speed of air flow 0.1 m/s.

All experimental tests showed that when the airflow speed is reduced (from 0.1 down to 0.02 m/s), the period of contact between the pollutants and the charge becomes longer and the effect of biological air cleaning is better.

4. Conclusions

1. Capability of microorganisms to biodegrade VOC effectively depends on pollutant concentration, air flow rate, quantity of charge, temperature, moisture content and special depends on pH value in the biomedium. The optimal efficiency of biological air treatment is at pH=7.
2. Performed efficiency investigations of biofilter with activated pine bark charge changing hydrogen ions concentrations and it was determined, that microorganisms grow in the neutral biomedium intensively. For example: butanol $C=5 \text{ mg/m}^3$, $E=98 \%$). While at another pH values: when pH=4, $E=6.9 \%$; when pH=5 then $E=49 \%$, when pH=6 then $E=91.1 \%$, when pH=8 then $E=91.1 \%$, when pH=9 then $E=49 \%$, when pH=10 then $E=8.6 \%$.
3. Experimental investigation treating butanol, butyl acetate and xylene show, that polluted air at pH=7 value is treated from butanol greater than butyl acetate or xylene (while $C=5 \text{ mg/m}^3$, $E=98 \%$), butyl acetate is treated 2 % less efficiency ($C=4 \text{ mg/m}^3$, $E=96 \%$), treating xylene the efficiency of treatment is 81 %, while $C=7 \text{ mg/m}^3$.
4. The results of analyses show, that the efficiency of biological air treatment vary depending on primary pollutants concentrations and supporting pH, for instance: treating air from xylene, when $C=96 \text{ mg/m}^3$, pH=6 or 8, it is determined, that the efficiency of filter is $E=49.3 \%$. When biomedium has pH=5 or 9, a concentration of xylene $C=96 \text{ mg/m}^3$, $E=26.5 \%$. Xylene $C=48 \text{ mg/m}^3$, pH=6 or 8, then $E=69.8 \%$, when concentration of xylene $C=48 \text{ mg/m}^3$, pH=5 or 9, then $E=37.5 \%$. To minimise the concentration of xylene till

7 mg/m^3 , pH=6 or 8, the efficiency of filter reaches 5.3 %, pH=5 or 9, $E=40.5 \%$; pH=4, $E=5.7 \%$; pH=10, $E=7.1 \%$. It can be seen, that filter work effectively at less polluted air concentration and neutral pH.

5. Performed analysis at pH=7 and it is determined, that the efficiency of filter depends on layer number and height. Bigger number of layer and height influence better efficiency of treatment, for example: spent butyl acetate, which has concentration $C=31 \text{ mg/m}^3$ through one layer of 15 cm height, the efficiency reaches 85.2%, while spent through 5 layers of 75 cm height, the efficiency reached 95.6 %.
6. Performed experimental investigations with different air flow rate, while pH=7, it is ascertained, that less velocity of air flow influence effective air treatment, for example: when air flow rate is 0.02 m/s the efficiency treating air from butanol, which has the concentration $C=98 \text{ mg/m}^3$ reaches 95.3 %, while velocity is 0.1 m/s, the efficiency of treatment decreases till 78.4 %.

References

- Aizpuru, A.; Malhautier, L.; Roux, J.; Fanlo, L. 2003. Biofiltration of a Mixture of Volatile Organic Compounds on Granular Activated Carbon. *Wiley periodicals* DOI: 10.1002/bit.10691.
- Akao, S.; Tsuno, H.; Horie, T.; Mori, S. 2007. Effects of pH and temperature on products and bacterial community in l-lactate batch fermentation of garbage under unsterile condition. *Water research*, 41: 2636 – 2642.
- Baltrėnas, P.; Vaiškūnaitė, R. 2003. Microbiological investigation of activated pine bark charge for biofilters. *Journal of Environmental Engineering and Landscape Management*, (10)1: 3–9.
- Baltrėnas, P.; Vaiškūnaitė, R. 2004. A biofilter containing a biologically active layer of pine bark for removing volatile hydrocarbons from air. *Industrial ecology. Chemical and Petroleum Engineering*, 40: 7–8.
- Baltrėnas, P.; Vaiškūnaitė, R.; A. Zagorskis. 2005. Experimental Studies of Air Flow Rate and Aerodynamic Resistance of Biological Air Purification Device that Contains Activated Fir Bark Charge. *6-osios tarptautinės konferencijos „Aplinkos inžinerija“, įvykusios Vilniuje 2005 m. gegužės mėn. 26–27 d.; pranešimų medžiagos*, Vilnius: Technika, 25–29.
- Baltrėnas, P.; Vaiškūnaitė, R.; Špakauskas, V. 2004. Experimental study and mathematical modelling of biofilter aerodynamic resistance. *Journal of environment engineering and landscape management*, (13)3: 79–84.
- Baltrėnas, P.; Zagorskis, A. 2009. Investigation of cleaning efficiency of a biofilter with an aeration chamber, *Journal of Environmental Engineering and Landscape Management*, 17(1).
- Baltrėnas, P.; Zagorskis, A. 2010. Investigation into the air treatment efficiency of biofilters of different structures, *Journal of Environmental Engineering and Landscape Management* 18(1): 23–31.
- Baltrėnas, P.; Zagorskis, A. 2007. Investigation into determining the humidity of charge used for biological air treatment. *Journal of Environmental Engineering and Landscape Management* 15(4): 193–199.

- Baltrenas, P.; Zagorskis, A. 2008. Investigation of cleaning efficiency of biological air-treatment device with activated charge of different origin, *Journal of Environmental Engineering and Landscape Management* 16(3): 113–120.
- Baltrėnas, P.; Zagorskis, A. 2008. Quantitative microbiological investigation of activated foam and zeolite charges used for biological air treatment. *The 7th International Conference "Environmental Engineering": Selected Papers (26–27 May 2008 Vilnius, Lithuania)* 1: 57–64.
- Chan, W.; Hwang, I. 2006. Biochemical kinetic behaviors between n-butyl acetate and composite bead in biofilter. *Appl Microbiol Biotechnol*, 73: 226–233.
- Gaudin, F.; Andres, Y.; Cloirec, P. 2007. Packing material formulation for odorous emission biofiltration. *ScienceDirect: Chemosphere*, 70: 958–966.
- Gunsch, C.; Kinney, K.; Szaniszló, P.; Whitman, C. 2007. Relative Gene Expression Quantification in a Fungal Gas-Phase Biofilter. *Biotechnology and Bioengineering*, 98(1).
- Li, L.; Wang, S.; Feng, Q.; Liu, J. 2008. Removal of o-xylene from off-gas by a combination of bioreactor and adsorption. *Asia-Pac. J. Chem. Eng.*, 3: 489–496.
- Liang, J.; Chiaw, L.; Ning, X. 2006. Application of Biological Activated Carbon as a Low pH Biofilter Medium for Gas Mixture Treatment. *Biotechnology and Bioengineering*, 96(6).
- Mcnevin, D.; Barford, J. 2000. Inter-Relationship between Adsorption and pH in Peat Biofilters in the Context of a cation-exchange mechanism. PII: S0043-1354(00)00305-5.
- Nievas, M. L.; Commendatore, M. G.; Esteves, J. L.; Bucala, V. 2005. Effect of pH modification on bilge waste biodegradation by a native microbial community. *International Biodeterioration & Biodegradation*, 56: 151–157.
- Vaiškūnaitė, R.; Miškinytė, D. 2008. Temperature Effects on Biofiltration by varying Biofilters Parameters. *The 7th International Conference Environmental Engineering: selected papers: May 22-23, 2008 Vilnius, Lithuania*. 1: 423–432.
- Vaiškūnaitė, R. 2008. Mathematical modelling of Biofilter's temperature regimes. *The 7th International Conference Environmental Engineering: selected papers: May 22-23, 2008 Vilnius, Lithuania*. 1: 433–441.
- Vanloon, G.; Duffy, S. 2005. Environmental chemistry a global perspective. Second Editon. Oxford university press. 516.
- Zigmontienė, A.; Vaiškūnaitė, R. 2005. Application of the Biological air purification technologies. *6-osios tarptautinės konferencijos „Aplinkos inžinerija“, įvykusios Vilniuje 2005 m. Gegužės mėn. 26–27 d.; pranešimų medžiagos*, Vilnius: Technika, 311–315.
- Zigmontienė, A.; Zuokaitė, E. 2010. Investigation into emissions of gaseous pollutants during sewage sludge composting with wood waste. *Journal of environmental engineering and landscape management*, 18(2): 128–136.