Experimental Study of Droplet Biofilter Packed with Green Sphagnum

Erika Petrauskaitė[1], Rasa Vaiškūnaitė[2]

Department of Environment Potection, Faculty of Environmental Engineering,
Vilnius Gediminas Technical University, Vilnius, Lithuania
E-mails: [1]erika.petrauskaite@stud.vgtu.lt (corresponding author); [2]rasa.vaiskunaite@vgtu.lt

Abstract. Air cleaning from VOC (volatile organic compunds) group of contaminants could be done by using different types of methods: adsoption, absorption, chemical or thermal oxidation. However, the most promising method is biological air cleaning. Biofilters have found most of their success in the treatment of dilute high-flow waste gas sreams containing odors or volatile organic compounds. To evaluate the meaning of the applicability of green sphagnum use in the droplet biofilter we will make the research. Sphagnum as a plant has big capabilities to absorb water and hold it in the porous parts plant structure. This characteristic of the plant could affect the water flow in the lower layer of the biolfiltrer and in this case will change the possibility to microorganisms to create right envinment to absorb and degrade the polluted air. The main aim of this research is the experimental study of droplet biofilter packed with green sphagnum.

Keywords: droplet biofilter, green sphagnum, air cleaning, volatile organic compounds.

Conference topic: Environmental protection.

Introduction

Volatile organic compounds (VOC's) are organic odours that comes from various industries emissions of gases from certain solids and liquids. As volatile organic compounds are the ones that contains carbon and could be part of carbon monoxide, carbon dioxide, carbon acid and other pollutants that participates in atmospheric photochemical reactions. Large amounts of contaminant air emissions of VOC and sunlight creates hazard smog.

Smog is harmful to human health and ecosystems that is arrounds us. To control harmful effects of VOC's, they should be treated using special control systems.

VOC's have high vapour pressure in standart conditions (20 ºC and 760 mm Hg) that gives eccess to different ways of treating air. Cleaning VOC group of contaminants could be done by using different methods: adsoption, absorption, chemical or thermal oxidation.

However in many various types of cleaning technologies, the most promising way – biofiltration that contains adsorbtion and absorbtion and degradation methods.

Biofiltration nowadays is one of the recent air pollution control (APC) technology. As the Z. Shaeefdeen, A. Singh (Shareefdeen, Singh 2005) noted in their book: biofilter is also the most basic technology for air treatment. The concept of using this technology is based on when the air is loaded with pollutants it flows through a wet packing material, called – load, that supports microorganisms which removes environmentally undesirable compounds. As the pollutants go through the load they are transferred in to aqueous liquid film coating the solid support, and then being degraded by bacteria in biodegradation process.

Technology offers the most economical and environmentally benign method for air pollution control when dealing with removal of odorous and toxic contaminants from industrial and municipal airstreams (Shareefdeen, Singh 2005).

The main advantages of biofiltration technologies are:
- effective technology for air stream contaminated with VOC's (Table 1);
- low initinial cost – that appears because of low temperature needs in oxidation processes;
- low annual operation cost – the are two main operational equipment that needs to be maintained: fan for the gas stream and circulation pump for humidification;
- low maintenance – bassicaly no big moving parts, just few operatonal equipment that needs maintenance;
- low pressure changes – as the pressure drop is low it saves power consumption in use of fan;
- environmental friendly – because have no conditional pollutant emissions and for the filter load use natural substances.

To summarize all the possitive aspects of biofiltration technology we can say, that it proves to be economcally good technology, that consists in low costs, effectiveness, good stable construction and environmental friendly substances.

Table 1. Biodegradability of various contaminants in a biofilter (Devinny et al. 1999)
(*Note: 1 – some biodegradability; 2 – moderate biodegradability; 3 – good biodegradability; n – unknown)

Contaminants	Biodegradability*
Aliphatic hydrocarbons:	
Methane	1
Propane	n
Butane	n
Aromatic hydrocarbons:	
Benzene	2
Toluene	3
Xylene	2
Aldehydes:	
Formaldehyde	3
Acetaldehyde	3
Alcohols:	
Methanol	3
Ethanol	3
Butanol	3
Ketones:	
Acetone	3
Methyl ethyl ketone	3
Inorganic compounds:	
Ammonia	3
Hydrogen sulfide	3

But as any other technologies it has it's own disadvantages:
– treat effectivelly only the VOC's with high adsorbtion and degradation rates;
– takes a time period for acclimation for the microbal population and it could take from week to months;
– Can not uptake high concentrations of pollutants, because it effect the microbes in the filter;
– for large amounts of contaminants require large unit of area for biofilter installation.

All these negative points that were mentioned, in biofiltration technology could be solved by wisely taking in to account the situation of pollution. It means, that the main things that needs to be taken in to account are the pollutant, amount, concentration and time. Usually these parameters are being looked out in choosing the right cleaning technology. We can say, that efficiency mainly depends on situation and how the main parameters of biofilter are choosen (Aplinkos apsaugos agentūra 2011).

Biofilter parameters

To know how efficiently use biofilter the main parameters should be clear. Biofilter has 7 main parameters that are considered to be the most important. Maintenance and monitoring are the basic points that needs to be considered too.

Microorganisms – degradation process is well known to be involved with microorganisms including bacteria, actinomycete and fungi. Metabolisms process and activity of microorganisms depend on presence of dissolved oxygen in the biofilm, the absence of compounds that are toxic to microorganisms, the availability of nutrients, sufficient moisture and suitable ranges for temperature and pH.

Second important thing is *filter construction* (Figure 1) *and sizing*. The type of construction and installation of biofiltration equipment for a given application will depend primarily on the availability of space relative to the required filter volume. Other criteria include differences in capital cost and maintenance requirements between the different systems.

Third one ir *filter material.* In order to have a biofilter to operate efficiently, the filter material must meet several requirements. First as it is mentioned earlier, it must provide optimum environmental conditions for the resident microbial population in order to achieve and maintain high degradation rates. Second, filter particle size distribution and pore structure should provide large reactive surfaces and low pressure drops. Third, compaction should be kept to a minimum, reducing the need for maintenance and replacement of the filter material − load (Arulneyam, Swaminathan 2005; Khan, Ghosal 2000; Operation and maintenance manual 2005) (Table 2).

Raw-Gas conditioning – since biofilters can be poisoned by the presence of off-gas constituents that are toxic to microorganisms because of their chemical nature and/or by excessive concentration, a characterization of type and

quantity of all off-gas constituents should always be conducted prior to the design of a filter. The elimination of a substance which is toxic to microorganisms from the emitting process, can make the off-gas suitable for biofiltration.

Moisture control − maintaining optimal moisture content in the filter material is the major operational requirement for a biofilter. Without providing additional moisture, the (usually unsatured) raw gas would quickly dry out the filter bed. Moisture is essential for the survival and metabolism of the resident microorganisms and contributes to the filters buffer capacity. In most biofilter installations the raw gas is humidified in a spray humidifier.

Table 2. Some reported elimination capasities for organic media (Sorial et al. 1997)

Compound	Medium	Inlet gas concentration (ppm)	Elimination capacity $(gm^{-3}h^{-1})$
Toluene	Compost	300	20
Toluene	Soil	1200−2500	1.73
Toluene	Compost	50	11.6
H_2S	Peat	0.04−70.7	18
Methyl mercaptan	Compost	7−25	2.58
Acetone	Compost	500−800	40
H_2S	Compost	8−20	15
H_2S	Wood bark	10	18

Control of pH. Since most microorganisms prefer a specific pH range, changes in the pH of the filter material will strongly affect their activity. Depending on the type of microorganisms that are present, the resulting drop in the pH can destroy the resident population and reduce, if not eliminate, the filter's degradation capacity. In such cases chemical buffers such as lime, are added.

Back Pressure and Energy Consumption. In a biofilter, (electrical) energy is predominantly needed by the blower to overcome the filters back pressure and to a lesser degree, by the humidifier. Typical pressure drops for different filter materials as a function of the surface load. Proper selection of the filter material will reduce pressure drop and the need for its maintenance and replacement.

Maintenance. It is the number of operations, that being done to make sure, that biofilter is working properly. A daily check of the major operating parameters, such as the off-gas temperature and humidity, temperature and back pressure should be checked. Some systems are controlled automatically.

Monitoring – mainly the controlling test to verify the efficiency that is claimed to be reached. The continuous off-gases are being tested with detectors, to make sure that total amount organic carbon is good enough.

When all of these parameters are being considered VOC's could efficiently eliminate VOC pollutants from that air is contaminated.

Methodology

For the experimental research the droplet biofilter that was created in Vilnius Gediminas Technical University were used. This biological air cleaning technological device will be filled with the green sphagnum load that was collected from the natural environment, and would be fractionated in differently and mixed with the peat moss.

The test stand is made from the biofilter frame that is the body of the device. The main characteristics of the stand are: 0.14 m of the diameter, 1.0 m of the height. The biofilter is connected with the circular water reservoir, pollutant supply chamber, the fan and rubber connecting tubes. In the biofilter there are 5 sections, every section is 10 cm height and diameter of 14 cm. Section layers are separated from each other with the metal grid. Polluted air will be passed through all the sections of the biofilter. The hole body of droplet biofilter stand was made from plastic (Figure 1).

Load of biofilter – peat. Peat is a plant that grows in swamps and has big capabilities to absorb water and hold it in the porous parts plant structure. Porocity characteristic of the plant can affect the water flow in the lower layer of the biolfiltrer and in this case will change the possibility to microorganisms to create right environment to absorb and degrade the polluted air. The single most important operating parameter for this load media is the bed moisture content. The optimal values range of humidity have to be between 50 and 60% for peat beds. If the bed becomes dry, then the medium will repel water, because of its hydrophobicity. So to contain the humidity, load was irrigating every second day.

The fan is the one who is responsible for the air flow management in the biofilter. After every section there is the special holes for the measurement of the parameters as air flow, pollution concentration and other. These holes are sealed with the with drawable rubber plugs.

When the circular water reservoir will be filled with the water and other amendments with the help of pump it will be provided to the top of the biofilter part where the injector will spray the water on the top of the sphagnum load uniformly in all parameter of the space. Sprayed water drops are connecting with the load and through the metal grids that connects the layers of sections goes to the lower sections of the biofilter. In this case all the layers are being activated in 20 days and makes the biological film.
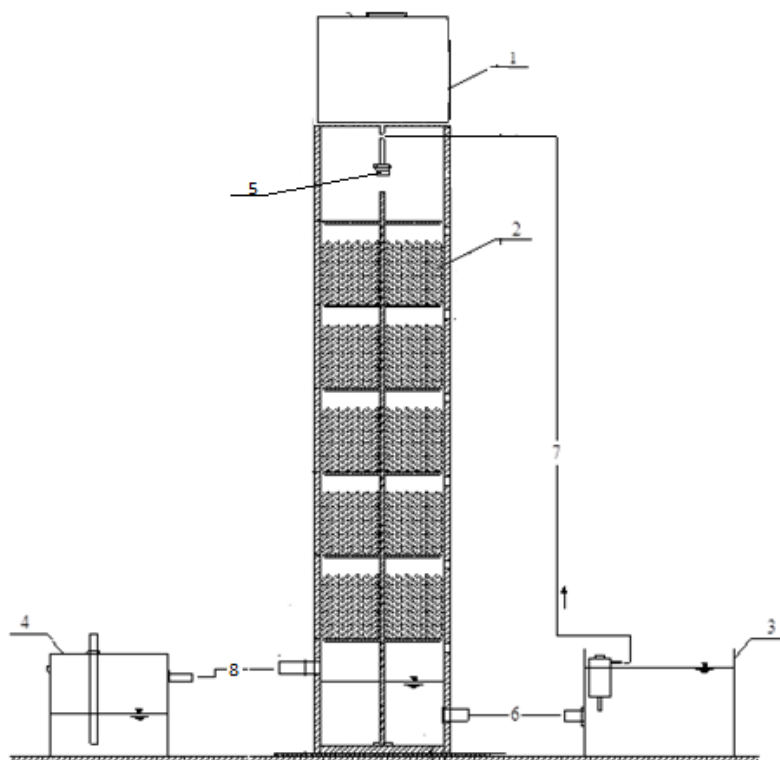
Fig. 1. Construction of the droplet biofilter: 1 – the fan for air traction; 2 – the load; 3 – circular water reservoir;
4 – pollutants supply to chamber; 5 – the water jet; 6, 7, 8 – rubber connecting tubes (Zagorskis, Spiečiūtė 2011)

When the film in the biofilter is equivalent in all five sections the water with the pollutant solution is being poured to get wanted concentration of the pollutant – acetone steams. As it was mentioned before, air system is being managed with the fan. Then the air with the steams of the pollutant are being supplied by vertical air flow, through all the biofilter sections. In the load the first thing that happens – microorganisms absorbs the pollutants that goes through with the air flow, and then later they are being biodegraded in the water phase. The air flow and the concentrations of the pollutants will be measured after every section – in total five sections. For the concentration measurement the American firm equipment will be used. "MiniRAE".

This device is using photo-ionization detector. The main advantages: lightweight and compact, dependable and accurate, user friendly, data logging capabilities. This device gives the real time measurements of gas concentrations in ppm. The vide specter of VOC could be determined.

The fan of air traction that is constructed on the top of the biofilter (Figure 1, point 1) layers has one air flow slot, the air could be pulled in one speed that is 0.08 m/s. The accuracy of the device, when air flow is 0.04−0.12 m/s range ± 5%.

To summarize: pollutant that we were analysing – acetone. Three different concentrations of it were omitted through the 5 layers biofilter load of green peat moss (lat. *Sphagnum*). Initial air flow in biofilter – 0.08 m/s in range of range ± 5%. Contaminant concentrations were – 400, 603 and 805 mg/m^3 in range ± 5%. 20 days after the acetone were engaged in the biofilter were given for load to adapt and grow microorganisms. First measurement was made in every layer using MiniRAE − 2000 device after 20 days and second – after 40 days (RAE Systems- MiniRAE 2000; Vaiškūnaitė 2004, 2008).

Results and discussion

The first measurement of biofilter efficiency values were done *after 20 days* using the same contaminant acetone and dependency of three different contaminant concentration values in five layers of biofilter (Figure 2). The values of efficiency varied from 66.50 to 71.59 % in range ± 5%.

In concentration of 400 mg/m^3 the highest efficiency in were reached in the last layer (height of 0.083 m) of biofilter – 71.59% range ± 5%. The lowest efficiency reached in the first layer (height of 0.097 m) – 69.18% range ± 5%.

In the concenctration of 603 mg/m^3 efficiency of biofilter varied in between 67.83 and 70.18% range ± 5%. The highest efficiency level was reached in the last layer (height of 0.083 m) of biofilter – 70.18% range ± 5% and the lowest efficiency in the first layer (height of 0.097 m) – 67.83% range ± 5%.
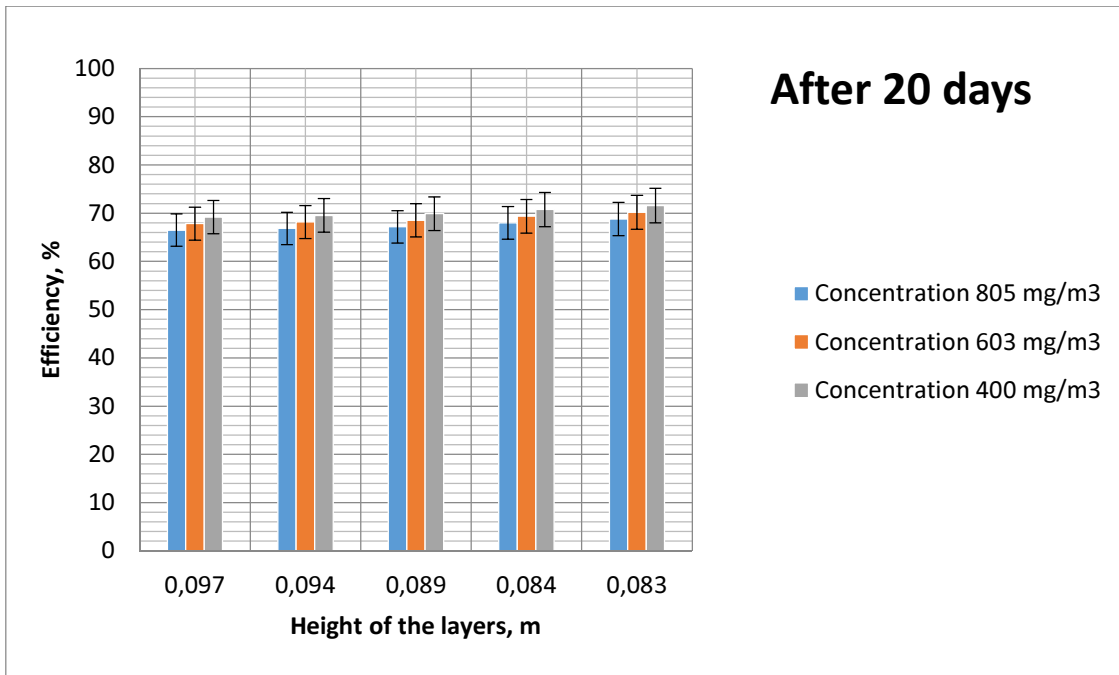
Fig. 2. Results of biofiltration efficiency in air cleaning process after 20 days acetone contaminant initiation to biofilter

Efficiency in concentration of 805 mg/m^3 varied from the lowest point in the first layer (height of 0.097 m) – 66.50% range ± 5% to highest point in the last layer (height of 0.083 m) – 68.81% range ± 5%.

The results of biofiltration efficiency after 40 days of contaminant – acetone initiation to the biofilter load in different biofilter layers in three different concentrations are given in Figures 3, 4. As it could be seen the efficiency of biofilter variated from 78.32 to 84.22% range ± 5%. The dependency of contaminant removal from the air stream depended on the high of the layer and the concentration value.

The highest efficiency in concentration 400 mg/m^3 were reached in the last layer (height of 0.083 m) of biofilter – 84.22% range ± 5%. The lowest efficiency reached in the first layer (height of 0.097 m) – 81.39% range ± 5%.

In the concentration of contaminant 603 mg/m^3 efficiency of droplet biofilter varied in between 79,80 and 82.57% range ± 5%. The highest efficiency level was reached in the last layer (height of 0.083 m) of biofilter – 82.57% range ± 5% and the lowest efficiency in the first layer (height of 0.097 m) – 79.80% range ± 5%.
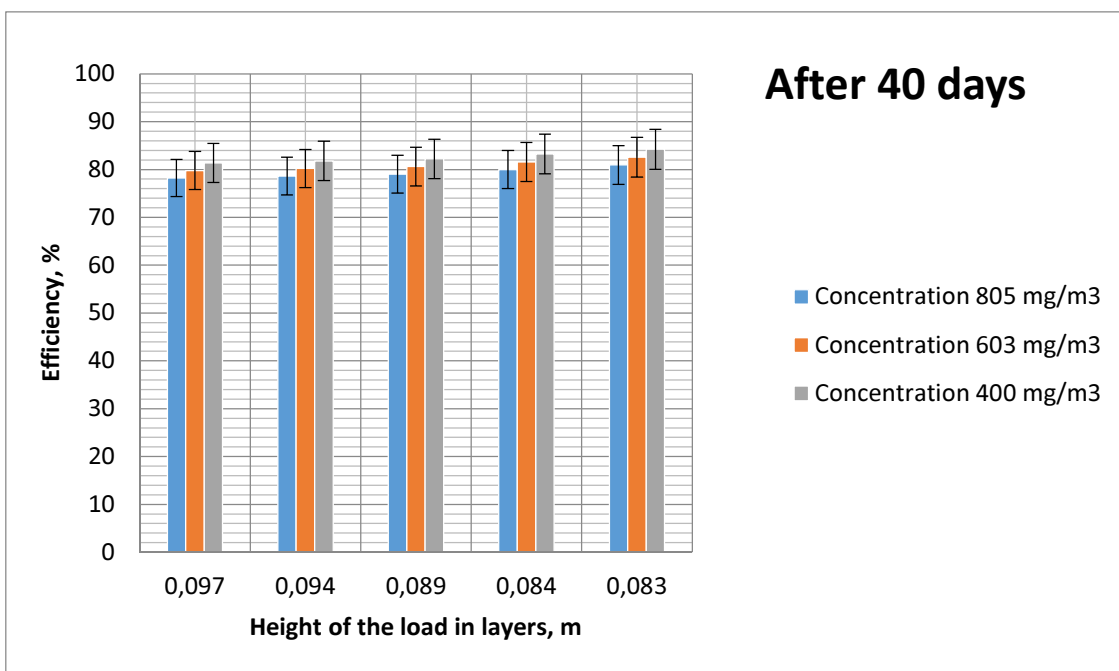

Fig. 3. Results of biofiltration efficiency in air cleaning process after 40 days acetone contaminant initiation to biofilter
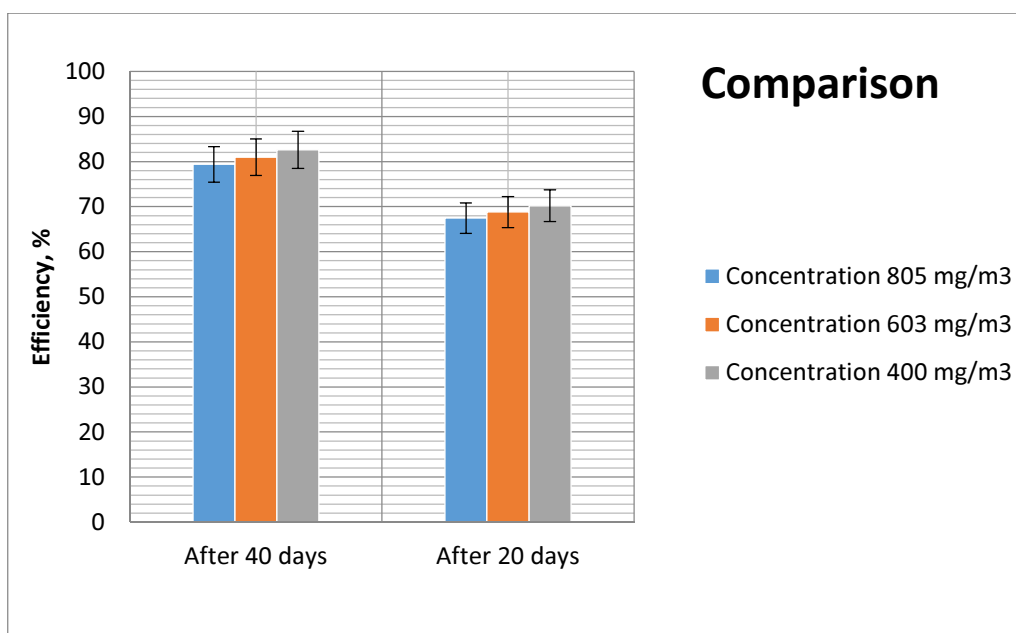
Fig. 4. Comparison of biofiltration average efficiency values in air cleaning process after 20 and 40 days
of acetone contaminant initiation

Efficiency with the acetone concentration of 805 mg/m^3 varied from the lowest point in the first layer (height of 0.097 m) – 78.23% range ± 5% to highest point in the days varied in about 2.77−2.83%, after 40 days – from 2.36 to 2.40%. These results gives the idea, that the amount of the layers in this situation last layer (height of 0.083 m) – 80.95% range ± 5% (Kim *et al.* 2000; Strack 2008; Wani *et al.* 1997, 2008).

Conclusions

Difference of efficiency in between the the first and the last layers in all concentrations after 20 days varied in about 2.77−2.83%, after 40 days – from 2.36 to 2.40%. These results gives the idea, that the amount of the layers in this situation did not have big influence in efficiency changes in biofilter.

In comparison of the efficiency in the time of experiment we can see that efficiency increased from average of 70.19% in all layers range ± 5% to 82.58% in all layers range ± 5% in the lowest contaminant concentration of 400 mg/m^3.

At the concentration of 603 mg/m^3 average efficiency values in time period from 20 to 40 days increased from 68.51 in range ± 5% to 80.96 in range ± 5%.

At the concentration of 805 mg/m^3 average efficiency values in time period from 20 to 40 days increased from 67.46 in range ± 5% to 79.37 in range ± 5%.

The efficiency after 40 days that was reached in different concentrations of 400, 603, 815 mg/m^3 was 84.22, 82.56 and 80.95% range ± 5%.

The changes of efficiency give clear view that the main obstacle in the efficiency of acetone cleaning with biofilter is the time and the initial concentration of the contaminant.

By the given results we can assume that peat moss as a medium – load of biofilter has capability to eliminate acetone contamination from the air stream after 40 days in efficiency up to 84.22% range ± 5%.

References

Aplinkos apsaugos agentūra. 2011(a). *Lakūs organiniai junginiai* [online], [cited 15 January 2015]. Available from internet: http://chemija.gamta.lt/cms/index?rubricId=8cd1f017-e3b0-4663-836e-979d1ba2cbe5

Arulneyam, D.; Swaminathan, T. 2005. Biodegradation of mixture of VOC's in a biofilter, *Journal of Environmental Science* 16(1): 30–33.

Devinny, J. S., *et al*. 1999. *Biofiltration for air pollution control*. Boca Raton (Fla.): Lewis Publishers, 299.

Khan, F. I.; Ghosal, A. K. 2000. Removal of volatile organic compounds from polluted air, *Journal of Loss Prevention in the Process Industries* 13(2000): 527–545. https://doi.org/10.1016/S0950-4230(00)00007-3

Kim, N. J.; Hirai, M.; Shoda, M. 2000. Comparison of organic and inorganic packing materials in the removal of ammonia gas in biofilters, *Journal of Hazardous Materials* B72: 77–90. https://doi.org/10.1016/S0304-3894(99)00160-0

Operation and maintenance manual [online]. 2005 [cited 15 May 2016]. Available from internet:

http://www.raesystems.com/sites/default/files/content/resource/FeedsEnclosure-MiniRAE_2000_RevE_0.pdf.

RAE Systems- MiniRAE 2000 [online]. 2016 [cited 15 May 2016]. Available from internet: http://www.raegasdetection.com/index.cfm?fuseaction=product.display&product_ID=19

Shareefdeen, Z.; Singh, A. 2005. *Biotechnology for odor and air pollution control.* Germany: Springer. 370 p. https://doi.org/10.1007/b138434

Sorial, G. A.; Smith, F. L.; Suidan, M. T.; Biswas, P.; Brenner, R. C. 1997. Performance of peat biofilter: impact of the empty bed resistence time, temperature and toluene loading, *Journal of Hazardous Materials* 53: 19−33. https://doi.org/10.1016/S0304-3894(96)01842-0

Strack, M. 2008. *Peatlands and climate change.* Finland: Publisher International Peat Society. 227 p.

Vaiškūnaitė, R. 2004. *Research on and application of the biofilter with activated pine bark charge for air purification.* Vilnius: Technika. 31.

Vaiškūnaitė, R. 2008. *Mathematical modelling of biofilter's temperature regimes*, in *the 7th International Conference Environmental Engineering* selected papers, May 22−23, 2008 Vilnius, Lithuania, Vol. 1: 433−441.

Wani, A. H.; Branion, R. M. R.; Lau, A. K. 2008. Biofiltration: a promising and cost-effective control technology for odors, VOCs and air toxics, *Journal of Environmental Science and Health*, Part A: Environmental Science and Engineering and Toxicology [online], [cited 16 May 2016]. Available from internet: http://www.tandfonline.com/loi/lesa19

Wani, H.; Branion, R. M. R.; Lau, A. K. 1997. Biofiltration: a promising and cost-effective control technology for odors, VOCs and air toxics, *Journal of Environmental Science and Health*, 1077−1204.

Zagorskis, A.; Spiečiūtė, R. 2011. Lašelinio biofiltro aerodinaminio pasipriešinimo tyrimai, *Journal of Science – Future of Lithuania.* ISSN 2029−2341 print / ISSN 2029−2252, 2011 3 (5): 64–69.