MOKSLAS – LIETUVOS ATEITIS
SCIENCE – FUTURE OF LITHUANIA

ISSN 2029-2341 print / ISSN 2029-2252 online
2013 5(4): 382–387 doi:10.3846/mla.2013.61

Aplinkos apsaugos inžinerija
Environmental Protection Engineering

REMOVAL OF SO_2 FROM CONTAMINATED AIR USING A PEAT BIOFILTER

Kristina Skemundrytė [1], Rasa Vaiškūnaitė [2]
Vilnius Gediminas Technical University
E-mail: [1]sk.kristina@yahoo.com; [2]rasa.vaiskunaite@vgtu.lt

Abstract. About 64 thousand tons of contaminated air is annually released into ambient air. More than 30% of such pollution includes toxic sulfur compounds. The article discusses the properties of biofiltration - biological air cleaning technology. Research was performed using a biofilter produced in the laboratory at Vilnius Gediminas Technical University. During testing, ambient air contaminated with sulfur dioxide was pulled through biomedia with a division of *Thiobacillus* microorganisms, and calculations of cleaning efficiency were performed. Besides, the efficiency of the charged peat biofilter (changing technical characteristics of the air flow rate, number of layers and value of pollutant concentration), depending on the nature of the investigated sulfur compounds and their concentrations, was determined.
The biofilter improves the efficiency of air cleaning when the air flow rate reduces from 0,1 to 0,02 m/s (e.g. when sulfur dioxide is used for treating the air flow rate under the initial concentration C = 15 mg/m³, the efficiency of the filter is equal to E = 96,3%).

Keywords: sulfur compounds, biofilter, biofiltration process, peat media.

Introduction

The major concern of these times in both developed and developing countries is the rapid growth of industry and energy sectors that cause growing emissions in ambient air. 30% of pollution includes sulfur compounds toxic for humans and environment (emission levels of sulfur compounds in ambient air compared with other pollutants, 2010), 25% of which makes sulfur dioxide.

According to data provided by the Ministry of Environment of the Republic of Lithuania and received from annual air monitoring, the total amount of emission has slightly increased since 2005. At the start of the economical crisis (in 2009), it decreased by 4%. However, transportation and energetics have remained the major problems since 2008 (Fig. 1).

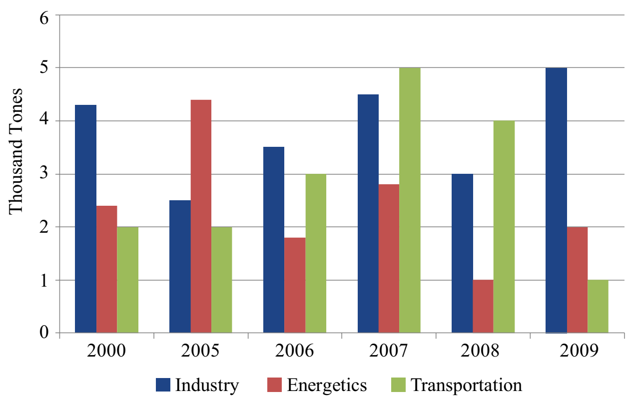

Fig. 1. Ambient air pollution in Lithuanian industry and the sectors of energy and transport for the period 2000–2009 (Ministry of Environment)

In 2010, approximately 20 thousand tons of sulfur compounds were emitted to the atmosphere from mobile (vehicular traffic, maritime vessels, aircraft, etc.) and stationary sources such as PLLC *Orlen Lithuania*, PLLC *Lifosa*, etc.

Sulfur compounds in ambient air can be cleaned using a variety of technologies: electrostatic, catalytic, absorbent, adsorptive method of cleaning air, etc. The chosen method is planned to be applied depending on the evaluation of advantages and disadvantages. The main criteria for determining the made choice is efficiency and cost considerations.

Since the beginning of the 20th century, an active interest in biological air purification technology has developed. This method makes it possible not only to ecologically clean the polluted air environment, but also install various types of equipment such as bark, rushes, straw, peat, activated sludge, etc.

Experimental investigation and assessment of the effectiveness of peat media made from sulfur compounds helps with making suggestions based on designing efficient and cost-effective biofilters for different industries (Chung *et al.* 2001, 2010; Hartikainen *et al.* 2000, 2011; Omri *et al.* 2011; Philip,Deshusses. 2003; Wang, Li 2011; Vani *et al.* 2000).

Biological air cleaning

The method of biological air purification, compared to other methods, is more useful, i.e. has a number of important advantages such as easy to use, a high degree of pollution elimination, low economic cost and the air purifier emits non-hazardous decomposition products (Baltrėnas *et al.* 2004).

Biofiltration is control technology for environmental pollution. It helps in controlling emissions of organic and inorganic (including sulfur) compounds having unpleasant odours and harmful effects on human health, the environment, atmosphere and workplace.

Fundamental biological air treatment systems, including bio-aeration (adsorption) equipment, bio-scrubbers and biofilters are used worldwide.

Ambient air pollution controlled with the help of biofilters is mainly based on two processes: organic matter with air is absorbed by media microorganisms, and microorganisms easily decompose absorbed materials with an increase in biomass in water.

The review of literature on design and operation of a biological air treatment system shows that effectiveness depends on the following key features (Kim, Deshusses 2008):

- configuration, size and flow sequence of the reactor;
- types of used bio-media and its characteristics;
- operating conditions such as air flow, reactor lifetime, water and nutrient availability;
- temperature, pressure and pH level of charge.

The advantages of the biofilter are as follows:

- the main uses of biofiltration for cleaning ambient air compared with other methods are lower investment, lower operating costs, low use of chemicals and no combustion which therefore does not cause further pollution;
- biofiltration equipment can be designed to physically fit into any size of an industrial area: there may be any size or shape in the open air or closed room;
- biofiltration is a quite versatile method that can be used for removing both with unpleasant odour toxic compounds in ambient air for cleaning, as well as may contain volatile organic compounds. Cleaning efficiency at low emission levels may reach more than 90%.

Charged biofilter

Biofilter media is essential biological air treatment equipment playing a key role in the application of organic pollutants to contaminated air. Biomedia can be natural (peat, compost, soil, pine bark, etc.) and artificial (plastic beads, glass beads, ceramics, foam, etc.) (Baltrenas *et al.* 2004).

Biomedia induced the activation of nutrient-rich irrigation water. Air cleaning contaminant molecules slowly passed through the charge. The molecules from the gaseous to liquid phase transmitted through the charge arising from the fermentation process (Wang, Li 2011).

Peat effectively cleans different types of pollutants. As shown by studies, turf pretty well keeps heavy metals, for example, treatment efficiency of lead makes from 35 to 100%, that of zinc – 17–96,9%, nickel – 21,3–96,4%.

Peat is usually composed of carbon (C) – about 35%, hydrogen (H) – about 4%, sulfur (S) – about 0,3%, nitrogen (N) – 5% and ash – about 35%. The main components of peat ash are Si, Al, Fe, Ca, Mg, Na and P. They constitute 90% of ash composition. The rest can be found in more than 40 kinds of trace elements.

Biofiltration process

The biological air cleaning process and organic and inorganic pollutants are divided into the harmless products of decomposition – carbon dioxide and water. The followed process plays a central role in biomedia cultivated microorganisms: bacteria, fungi, yeasts, etc. (in this particular case, sulfur dioxide during an active division of *Thiobacillus* microorganisms).

The degradation of pollutants may be carried out under aerobic (oxygen in the atmosphere) and anaerobic (no oxygen in the atmosphere) conditions.

Figure 2 shows that the pollutant degradation process occurs during the biofiltration process. Pollutants in the biofilm are transported by diffusion and absorption.

The current technological progress in biological air purification eliminates the disadvantages of used biofilters.

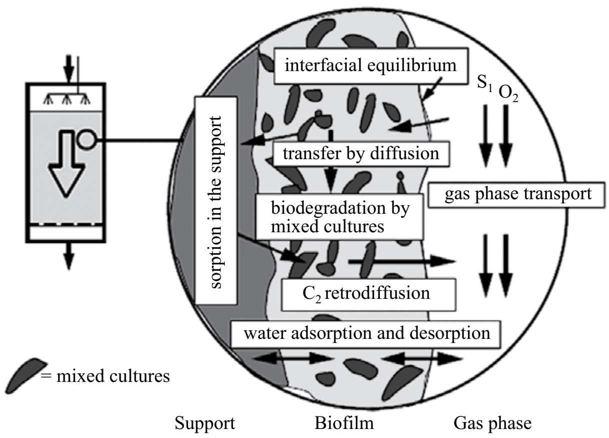

Fig. 2. Biofiltration process

Research methodology

The study on the biofilter was carried out at the laboratory of the Department of Environmental Protection at Vilnius Gediminas Technical University. Experimental investigation included ambient air cleaned from sulfur dioxide).

The biofilter (0,5×0,48×2,0 m) equipped with a biologically activated charge contains five separate layers of biomedia that mutually do not press each other, are separated by meshes and ensure even distribution of the air flow.

When purifying air from the sulphur dioxide of organic nature, the flow of polluted air is blown through all five layers of bio-medium with the help of a ventilator. The dampers with control handles in the inlet and outlet ducts of the filter to adjust the air flow (56,7 to 144,69 m^3/h) and flow velocity (0,02 to 0,1 m/s) are installed. In order to increase the amount of polluted air, the inlet air duct has a funnel shape at the front end. Purified air is exhausted through the flexible duct from the filter.

As the temperature in the charge of the filter was maintained, the medium was heated using two elements installed in the side walls of the filter (Vaiškūnaitė *et al.* 2004).

Prior to starting the biofilter, the medium was moistened and biogenic elements were added. Then, the medium was biologically activated by blowing organic pollutants through it.

The humidity of the charge was periodically monitored applying the weighting method and desiccating peat samples at a temperature of 100–105 °C until constant weight was obtained. Microorganisms in the charge also require biogenic elements: nitrogen (N), phosphorus (P), magnesium (Mg), sulphur (S), etc. Biogenic elements are consumed by microflora in the charge together with water. Therefore, the prepared solution of nutrients is poured into the water tank and sprinkled together with water above each layer of biomedium. To obtain stable pH, $CaCO_3$ salt solution was produced and supplied at least once a week.

All measurements of concentrations are made following the air cleaning process using biofilter media. The source has been drawn artificially inducing a chemical reaction between a sodium sulfide saturated solution of concentrated sulfuric acid:

$$Na_2\,SO_3 + H_2\,SO_4 \rightarrow Na_2\,SO_4 + H_2O + SO_2, \quad (1)$$

A chemical reaction was induced by the installation of sulfuric acid to sodium sulfite solution.

For experimental investigation, peat briquette fractions of different size (10–30 cm and 30–60 cm) were selected. In order to cultivate microorganisms, the charge was maintained at a constant temperature (28 °C) and moisture regime (68%) for one month. The size of peat fraction was chosen having analyzed the results of worldwide performed experiments, i.e. a charged fraction smaller than 0,6 m is more effective, as in this case, a certain volume of the biofilter is filled with a higher amount of material, and the level of porosity is higher. Biological air cleaning efficiency can be influenced by changes in temperature (25–32 °C).

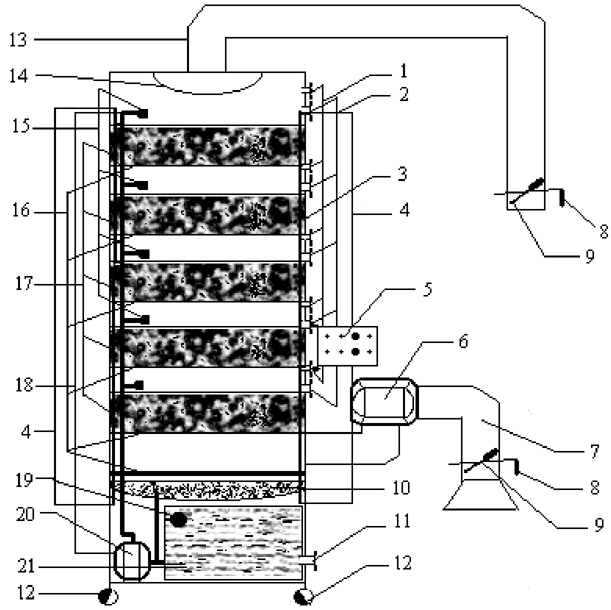

Fig. 3. Scheme for the biofilter with a fixed biologically active medium layer (Baltrėnas *et al.* 2004): 1 – measurements of the hole (Ø 15) using a crane, 2 – measurements of the hole (Ø 20) using a crane, 3 – filter housing, 4 – cleaning the heating element of the air heater, 5 – panel for device control, 6 – blowing fan of polluted air, 7 – inlet duct of polluted air (starting with a cover sheet), 8 – valve opening and closing a regulator handle, 9 –flow-control valve of the filter, 10 – waste collector, 11 – wastewater removal, 12 – damping wheel; 13 – clean air outlet duct; 14 – condenser lowering biomedium, drying and reducing its changes in temperature, 15 – water jets, 16 – separating layers of gauze; 17 – medium layer; 18 – irrigation system; 19 – recharge outlet, 20 – pumping water and the excess suction pump, 21 – water tank (Baltrėnas *et al.* 2004)

A reduction in temperature (<25 °C) influences the compaction of the charge, decreased circulation flows and the gradual formation of a specific odour emitting anaerobic environment. Under a higher temperature (>32 °C), microorganisms are more sensitive and therefore could die. Temperature is measured applying a thermometer TPK during each experiment. The quality of cleaned air is assured by maintained humidity conditions (68%). In the absence of medium humidity (<68%), the degradation of organic pollutants is less intensive as living organisms can no longer eat, grow and multiply, become inactive and after a certain amount of time can definitively die. An increase in humidity (>68%) promotes the formation of anaerobic conditions and shortens biomedia operation that was determined during each experiment using a psychrometer MV-4M.

Air flow velocity was measured in the biofilter during the experiments employing a device Testo 452 equipped with a Pito tube. Every measurement was performed five times. Air flow velocity was calculated in the following way:

$$w = 0{,}81r - 0{,}4951, \quad (2)$$

where w – true velocity of air, m/s, r – instrument readings, m/s.

In order to choose effective biomedia for the bio-filter, different fractions of charged peat briquettes were analyzed and their porosity was determined. These fractions included the peat samples of 10–30 and 30–60 mm.

During the experiments, the overall mass of the dry and wet charge of peat was measured (scale precision 0,00005 g). The density of peat media making 625 kg/m³ (dry charge) and 673 kg/m³ (68% humidity) as well as the volume of the chosen factions were estimated. The sample of peat media was poured into the cylinder of 1000 ml in volume. Next, the cylinder was weighted to determine their bulk density (Pρ, kg/m³), and porosity was calculated using the formula

$$P = 1 - \frac{\rho_P}{\rho_D} \cdot 100\%, \quad (3)$$

where P – porosity, %; ρ_P – bulk density of peat media, kg/m³; ρ_D – density of peat media, kg/m³.

Air samples were taken in the breathing zone using an electric aspirator connected to absorbent vessels. Air was pulled for 5 minutes at 20 l/min.

Determining the concentration of the sample was carried out using a spectrophotometer.

Sulfur dioxide concentrations in ambient air (mg/m³) were calculated by the formula

$$X = \frac{ab}{cV_0}, \quad (4)$$

where a – sulfur dioxide found in the analyzed volume, µg; b – the total volume of the sample, ml; c – the volume of the sample taken for analysis, ml; V_0 – the volume of the air taken for analysis, l.

The investigated concentrations of sulfur dioxide in ambient air, mg/m³ is the sum of concentrations obtained by calculating the first and second absorbent dish samples:

$$X = X_1 + X_2, \quad (5)$$

where X_1 – sulfur dioxide found in the analyzed sample of the first absorber (mg/m³); X_2 – sulfur dioxide found in the analyzed sample of the second absorber (mg/m³).

The efficiency of the biofilter (E, %) was calculated after determining SO_2 concentrations with the help of photometric analysis:

$$E = \frac{C_0 - C}{C_0} \cdot 100; \quad (6)$$

where C_0 and C – sulfur dioxide concentrations in the air before and after cleaning (mg/m³).

Results

Following 30-41-day biomedium activation, before every experiment, gradually increasing allowable sulfur dioxide concentrations and changes in the operating mode (allowed air flow rate, boot height, etc.) of the device have been studied taking into account the efficiency of the biofilter.

The overall removal efficiency of sulfur dioxide in the biofilter packed with peat is shown in Figure 4.

The measured porosity of this charge was equal to 52%. The above figure shows that the biofilter is effective at treating the air stream from low concentrations of sulfur dioxide. The removal efficiency of 93% was determined treating the polluted air stream up to 30 mg/m³.

For determining the effectiveness of the biofilter with a different fraction of peat media, a dramatic drop in removal efficiency was noticed (Fig. 5).

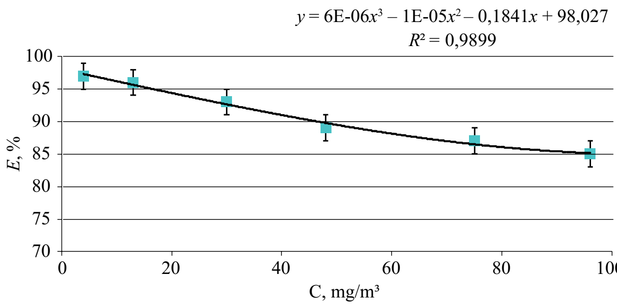

Fig. 4. The overall removal efficiency of sulfur dioxide (fraction size 10–30 mm, P = 52%)

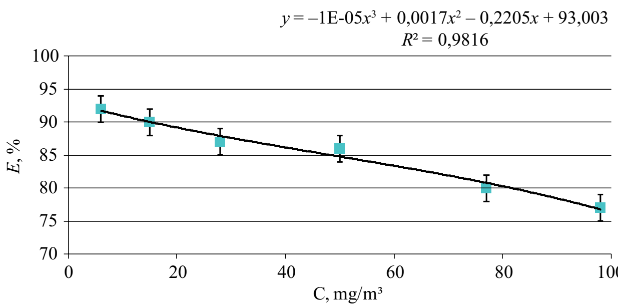

Fig. 5. The overall removal efficiency of sulfur dioxide (fraction size 30–60 mm, P = 76 %)

Figure 5 shows the overall removal efficiency of sulfur dioxide using a bigger fraction of peat media that has decreased from 93% to 86%. This result only explains the fact that the bigger fraction has a higher value of porosity and therefore contaminants are absorbed slower compared to the smaller fraction of peat media.

During the experiment, the efficiency of the filter was tested depending on the number of charged layers. An increase in the number of the layers from one to five resulted in the higher efficiency of air cleaning due to a greater amount of biomedia and higher concentration of microorganisms. When the number of the layers reached five, the efficiency of air cleaning under the same initial concentration was higher. The results of the removal efficiency of sulfur dioxide, depending on the height of the layer, are given in Figures 6 and 7.

Having injected the air of lower concentration (from 5 mg/m³ to 30 mg/m³), the efficiency of air cleaning, depending on the number of the layers from one to five, hardly differed (5–17%). For example, the efficiency of air cleaning from sulfur dioxide under the initial concentration of 5 mg/m³ and conditions of one layer was 94%, whereas that under five layers reached 98%.)

Having injected the air of lower concentration (4 mg/m³ to 14 mg/m³), the efficiency of air cleaning, depending on the number of the layers, made 7 – 15% using a higher fraction of peat media (30–60 mm). With an increase in initial pollutant concentrations, biofiltration efficiency changes depending on the number of layers and after one and five layers reaches 8%.

The following experiment involved the determination of removal efficiency according to the air stream flow rate. During the conducted experiment, the air polluted with sulfur dioxide was injected at a speed ranging from 0,02 to 0,1 m/s. The obtained results are shown in Figures 8 and 9.

Figure 8 shows the results of measuring the efficiency of peat media (fraction size 10–30 mm) having the porosity value of 52%. When pH = 7, the filter efficiency of 98% is achieved under the speed of sulfur dioxide with the initial concentration of 4 mg/m³ and flow rate of 0,02 m/s.

Accordingly, when the initial concentration of sulfur dioxide is up to 30 mg/m³, air may be injected at a speed of 0,08 m/s and even higher, which is the case when the efficiency of air cleaning reaches 86%. If the speed of the airflow passing the filter is increased to 0,1 m/s without

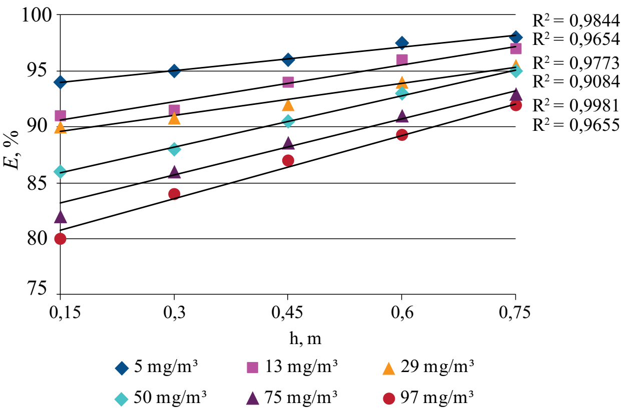

Fig. 6. Removal efficiency of sulfur dioxide according to the height of the layer (fraction size 10–30 mm, *P* = 52%)

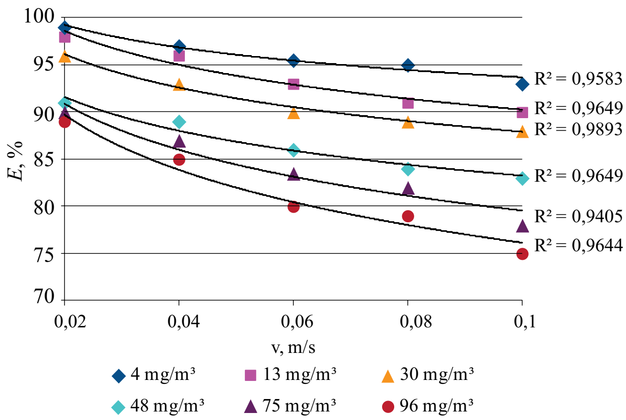

Fig. 8. Removal efficiency of sulfur dioxide according to the polluted air stream flow rate (fraction size 10–30 mm, *P* = 52%)

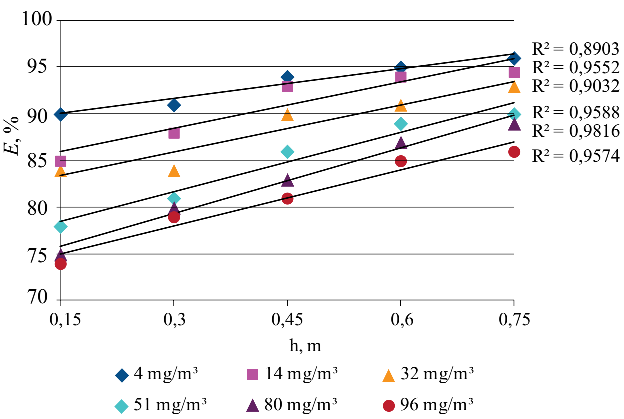

Fig. 7. Removal efficiency of sulfur dioxide according to the height of the layer (fraction size 30–60 mm, *P* = 76%)

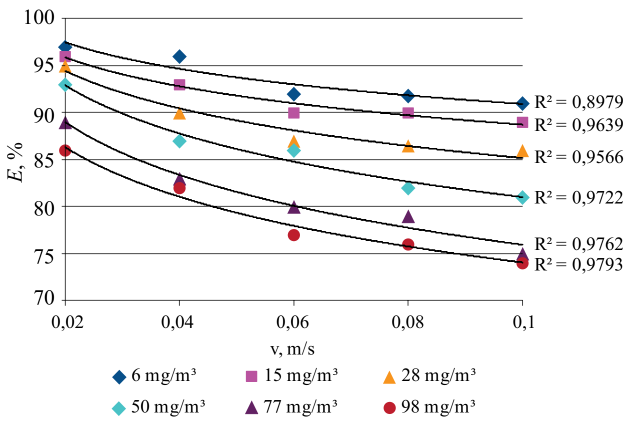

Fig. 9. Removal efficiency of sulfur dioxide according to the polluted air stream flow rate (fraction size 30–60 mm, *P* = 76%)

changing the above mentioned test conditions (under the initial pollutant concentration reaching 96 mg/m³), biofiltration efficiency decreases to 73%.

Figure 9 shows the results of measuring the efficiency of peat media (fraction size 30–60 mm) having the porosity value of 76%. The filter efficiency of 95% is achieved under the speed of sulfur dioxide with the initial concentration of 6 mg/m³ and flow rate of 0,02 m/s. If the speed of the airflow passing the filter is increased to 0,1 m/s, under testing conditions when the initial pollutant concentration makes 98 mg/m³, biofiltration efficiency decreases to 74%.

Conclusions

1. The made studies have shown that the efficiency of the filter cleaning from sulfur dioxide is highly dependent on allowable pollutant concentrations. The biofilter is best applicable to removing pollutants from the contaminated air stream when lower initial concentrations are present (4–24 mg/m³).
2. The efficiency of the biofilter cleaning air improves when the air flow rate is reduced from 0,1 to 0,02 m/s (e.g. sulfur dioxide treatment at the air flow rate of 0,02 m/s under the initial concentration C = 15 mg/m³ is equal to E=96,3%; when velocity increases up to 0,10 m/s, efficiency declines to 89,20%) as well as the height of the charge (from 150 to 750 mm) and the number of layers (from 1 to 5) rise.
3. The efficiency of the biofilter greatly depends on the fraction size of peat media. The experiments have showed that choosing a smaller fraction of peat (10–30 mm), the efficiency of the device improves by 10–15%, because a smaller fraction has a larger surface area and higher number of microorganisms.

References

AM – Aplinkos ministerijos duomenys. 2011 [online], [cited 22 October 2011]. Available from internet: http://www.am.lt

Baltrėnas, P.; Zingmontienė, A.; Vaiškūnaitė, R. 2004. *Oro valymo biotechnologijos:* monografija. Vilnius: Technika. 205 p.

Chung, Y.; Huang, C.; Tseng, P. 2001. Biological elimination of H_2S and NH_3 from wastegases by biofilter packed with immobilized heterotrophic bacteria, *Chemosphere* 43(2001): 1043–1050. http://dx.doi.org/10.1016/S0045-6535(00)00211-3

Chung, Y. C.; Cheng, C. Y.; Chen, T.; Hsu, J.; Kui, C. 2010. Structure of the bacterial community in a biofilter during dimethyl sulfide (DMS) removal processes, *Bioresource Technology* 101(2010): 7165–7168. http://dx.doi.org/10.1016/j.biortech.2010.03.131

Hartikainen, T.; Martikainen, P. J.; Olkonnen, M.; Ruuskanen, J. 2000. Peat biofilters in long-term experiments for removing odorous sulphur compounds, *Water, Air, and Soil Pollution* 133: 335–348. http://dx.doi.org/10.1023/A:1012966705004

Hartikainen, T.; Martikainen, P. J.; Ruuskanen, J. 2011. Carbon disulfide and hydrogen sulfide removal with a peat biofilter, *J. Air & Waste Manage*. 51: 387–392. http://dx.doi.org/10.1080/10473289.2001.10464275

Kim, S.; Deshusses, M. A. 2008. Determination of mass transfer coefficients for packing materials used in biofilters and biotrickling filters for air pollution control, *Chemical Engineering Science* 63: 841–855. http://dx.doi.org/10.1016/j.ces.2007.10.011

Omri, I.; Bouallagui, H.; Aouidi, F.; Godon, J.; Hamdi, M. 2011. H_2S gas biological removal efficiency and bacterial community diversity in biofilter treating wastewater odor, *Bioresource Technology* 102(22): 10202–10209. http://dx.doi.org/10.1016/j.biortech.2011.05.094

Philip, L.; Deshusses, M. A. 2003. Sulfur dioxide treatment from flue gases using a biotrickling filter-bioreactor system, *Environ. Sci. Technol.* 37: 1978–1982. http://dx.doi.org/10.1021/es026009d

Wang, H.; Li, H. B. 2011. Design and application of biofilter to control odor in wastewater treatment plant, *Energy Procedia* 11: 3965–3969. http://dx.doi.org/10.1016/j.egypro.2011.10.786

Vani, M.; Hirai, M.; Shoda, M. 2000. Enhancement of ammonia removal in peat biofilter seeded with enriched nitrifying bacteria, *Environmental Technology* 21(10): 1199–1204. http://dx.doi.org/10.1080/09593332108618039

SO_2 ŠALINIMAS IŠ UŽTERŠTO ORO NAUDOJANT BIOFILTRĄ SU DURPIŲ ĮKROVA

K. Skemundrytė, R. Vaiškūnaitė

Santrauka

Didžiausia šiais laikais išsivysčiusių ir besivystančių šalių problema yra greitai besiplečiančių pramonės ir energetikos sektorių į aplinkos orą išmetami cheminiai junginiai (apie 64 tūkst. tonų per metus), iš kurių apie 30 % – žmogui nuodingi ir aplinkai neigiamą poveikį darantys sieros junginiai. Trumpai aptariama biologinio oro valymo privalumai, pagrindinės pasirinktõs durpių bioįkrovos charakteristikos, pateikiama taikyta metodika bei sieros dioksido valymo iš oro eksperimentų rezultatai, aprašomas biofiltracijos procesas.
Biofiltro oro valymo efektyvumas didėja mažinant valomo oro srauto greitį nuo 0,1 iki 0,02 m/s (valant sieros dioksidu užterštą orą, kai pradinė teršalo koncentracija C = 15 mg/m³), filtro efektyvumas yra E = 96,3 %.

Reikšminiai žodžiai: sieros dioksidas, biofiltras, biofiltracijos procesas, durpių įkrova.