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Air treatment efficiency of biofilter with adsorbing zeolite layer

Alvydas Zagorskis*,

Pranas Baltrėnas

Department of Environment Protection, Vilnius Gediminas Technical University, Saulėtekio 11, LT-10223 Vilnius, Lithuania

The biological air treatment method is based on the biological destruction of organic compounds by employing certain cultures of microorganisms. This method is simple and may be applied in many branches of industry.

An air treatment biofilter with an adsorbing zeolite layer was used for an experimental study. The highest air treatment efficiency was achieved upon charging the device with an activated packing material composed of a mixture of wood chips, barks, zeolite and foam cubes. The device's treatment efficiency reached up to 98 ± 1% at the airflow rate of 0.1 m/s fed to the biofilter and the initial acetone vapour concentration 305 ± 30 mg/m^3. A higher air treatment efficiency of the biofilter was achieved when supplying the filter with air polluted with pollutant vapour of a higher concentration – 12 ± 45 mg/m^3.

To extend the useful life of a packing material, air treatment by applying a mixture of fir barks and wood chips, zeolite granules and foam cubes is recommended. The obtained results show that upon using these packing materials for biological air treatment, the biofilter treatment efficiency changes insignificantly, and the useful life of the packing material is extended. The chamber with the adsorbing zeolite layer, equipped before the biofilter, reduces by about 20% the concentration of the pollutant vapour supplied to the biofilter up to 20 ± 4%.

Key words: biofilter, biodestruction, acetone, microorganisms

INTRODUCTION

Presently, one of the most efficient and promising air treatment methods is biological air treatment using certain cultures of microorganisms (Deshusses, 1997; Miao et al., 2005). The main element of biological air treatment devices, biofilters, is a biofilter packing material (Ardjmand et al., 2005; Baltrėnas, Zagorskis, 2009).

In order to extend the useful life of a packing material in an air treatment biofilter and at the same time increase the device's treatment efficiency, biological (Zigmontienė, Baltrėnas, 2004) and adsorption (Jankevičius, Liužinas, 2003) treatment methods can be combined. As zeolite has a regular structure and pores of an identical size and is characterized by a large internal specific surface area as well as thermal stability, it is widely applied for air treatment as an adsorbent. Upon mixing wood chips and barks with zeolite, the packing material's service life will be extended and the sorption properties of the filtering medium improved (Cheng, Reinhard, 2006). The cultures of spontaneous microorganisms will be able to develop not only in wood chips, but also in zeolite of inorganic origin (Lu et al., 2004).

During the process of air treatment, molecules of the supplied pollutant are slowly moving through the charge. After being transferred from the gaseous to the liquid phase, they are degraded by microorganisms during fermentation processes occurring on the biofilm that has been formed on the charge (Ardjmand et al., 2005; Engesser, Plaggemeier, 2000).

Biofilters can be used for the sorbtion and degradation of pollutants such as acetone, butanol, toluene, methanol and other hydrocarbons. The devices can be used when the concentration of a pollutant does not exceed 500 mg/m^3. At higher concentrations, it is necessary to install the first step of purification.

Charges of the artificial origin, composed of polyurethane, propylene, polyethylene, glass, ceramic balls and other materials, are also often used. However, all these materials are destructed by microorganisms in the course of time (Yun, Ohta, 1998; Torkian et al., 2003).

* Corresponding author. E-mail: alvydas@vgtu.lt

The aim the present study was, by using activated packing materials composed of natural zeolite granules, foam cubes, barks and wood chips, to determine the dependence of the treatment efficiency of biofilters with an adsorbing zeolite layer on the nature, concentration and filtration time of a pollutant.

MATERIALS AND METHODS

Experiments were performed using a biological air treatment device, a biofilter, with an adsorbing zeolite layer (Fig. 1). The filter was equipped with five modules separated by metal sieves from each other.

The experiments were performed upon filling the modules with packing materials of different origin (Fig. 2) – initially with wood chips 20–30 mm in size. The volume ratio of wood chips and barks was 50 : 50. Afterwards, experiments were performed by charging the modules with wood chips and barks mixed with natural zeolite granules (10–15 mm). The volume ratio of chips, barks and granules was 33 : 33 : 34. Afterwards, experiments were performed by charging the modules with wood chips and barks 20–30 mm in size, mixed with foam cubes (30 × 30 × 20 mm). The volume ratio of chips, barks and foam cubes was 33 : 33 : 34. Later, experiments were performed by charging the modules with packing materials consisting of wood chips (20–30 mm), barks (20–30 mm), zeolite granules (10–15 mm) and foam cubes 30 × 30 × 20 in size. According to volume, the mixing ratio of wood chips, barks, zeolite granules and foam cubes was 25 : 25 : 25 : 25. The main characteristics of the materials are presented in Table.

Experiments with a single packing material lasted three weeks. The total experiment time was 12 weeks.

Each layer of the packing material was 0.75 m long, 0.55 m wide and 0.15 m high. After filling up the modules, the packing material was activated by maintaining the temperature at 30 ± 0.4 °C, the bio-medium acidity pH = 7 ± 0.1 and the required quantity of biogenic elements in the biofilter (Baltrėnas, Zagorskis, 2007; Koh et al., 2004). A constant temperature was maintained by a channel air heater installed in a polluted air-supply duct. To ensure microorganism growth and energy, a solution of mineral salts was necessary for the microorganisms to receive vital biogenic elements. The salt solution was composed of K_2HPO_4 – 1 g, KCl – 0.5 g, $MgSO_4 \cdot 7H_2O$ – 0.5 g, $FeSO_4 \cdot 7H_2O$ – 0.1 g, $NaNO_3$ – 0.90 g, water – 1 000 g. This solution was poured into a water reservoir and sprayed over each layer of the charge. To ensure microorganism metabolism, the acidity pH = 7.0 ± 0.1 was

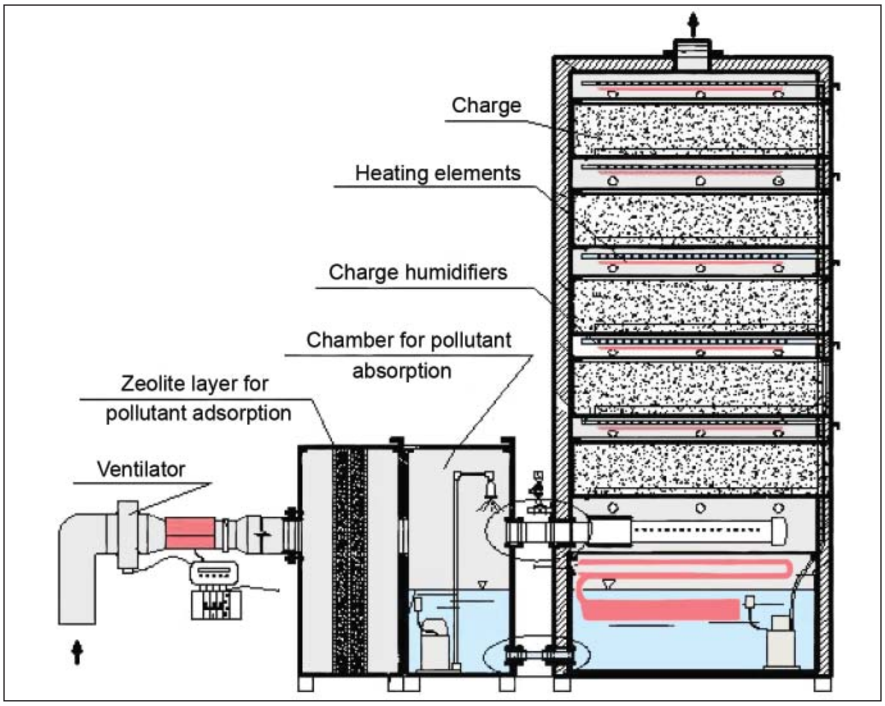

Fig. 1. Industrial-laboratory biofilter with adsorbing zeolite layer

Table. Main characteristics of the biofilter packing materials

Biofilter packing material	Volume ratio, %	Density, kg/m³	Porosity, %
Mixture of wood chips and barks	50 : 50	385	60
Mixture of wood chips, barks and zeolite granules	33 : 33 : 34	755	43
Mixture of wood chips, barks and foam cubes	33 : 33 : 34	255	85
Mixture of wood chips, barks, zeolite granules and foam cubes	25 : 25 : 25 : 25	540	52

maintained in the biomedium. Buffer solutions composed of sodium and potassium hydrophosphates were used to ensure the acidity. The biomedium's acidity was measured with a pH-metre (Baltrėnas, Zagorskis, 2009).

Different concentrations of acetone were passed through the charge for the maintenance of microorganisms' energy. Microorganisms use acetone as a source of energy by evolving the products of metabolism, i. e. CO_2 and water, into the environment. (Yoon, Park, 2002; Kleinheinz, Bagley, 1998).

As investigations show, microorganisms are best to destroy pollutants whose concentration does not exceed 500 mg/m^3. Volatile organic compounds are best decomposed at a lower initial concentration of a pollutant. At the initial pollutant vapour concentration 500 mg/m^3, the biofilter treatment efficiency reached 60%. Upon increasing the initial pollutant concentration to 1000 mg/m^3, the treatment efficiency of biofilters fell to 40% (Amanullah et al., 2000). Therefore, a primary treatment step consisting of a module filled up with zeolite granules was installed before the biofilter. A polluted air humidification unit was installed behind the zeolite layer intended for pollutant adsorption. Air in this unit was humidified to 95–100%; and in the presence of such humidity of the air supplied to the device, the activity of microorganisms in the packing material increased. Upon the biofilter starting up, the biofilter's packing material was additionally humidified with water sprayers installed above each of its layers (Fig. 1).

Different concentrations of acetone vapour (25 ± 5 to 305 ± 5 mg/m^3) were passed through the packing material to maintain microorganisms' energy (Jankevičius, Liužinas, 2003). The initial concentration of the supplied acetone reached 20 mg/m^3. The pollutant was supplied to the device four times a day for 15 minutes each time. Later, the concentration of the organic compound was increased by 20 ± 4 mg/m^3 every two days, and acetone supply duration was prolonged to 1 h. The charge was being activated for 2 weeks. To ensure a uniform airflow and pollutant concentration distribution over the entire area of the packing material, an airflow distribution collector was installed in the bottom part of the filter.

After the packing material activation, the device was supplied with air polluted with acetone vapour. The concentration of acetone before five layers of the packing material reached 305 ± 30 mg/m^3. To determine the pollutant's concentration, air sampling was done, maintaining a stable rate of the supplied airflow at 0.1 m/s. Upon sampling completion, the supplied airflow rate was increased to 0.2 m/s with a controllable airflow valve installed in the biofilter. Experiments were repeated by gradually increasing the supplied airflow rate to 0.3, 0.4 and 0.5 m/s.

The rate and temperature of the airflow passed through the packing material are recorded with a Testo 400 meter of environment's thermal parameters.

To determine the dependence of biological air treatment device's efficiency on the concentration of pollutants, the concentration of supplied acetone vapour was increased to 515 mg/m^3. The pollutant's concentration was changed by heating it on an electrical stove. Afterwards, experiments were repeated by increasing the initial acetone concentration to 712 ± 45 mg/m^3.

Upon completing experiments with acetone, unpolluted air was supplied to the device every 3 hours to accelerate the de-sorption of acetone vapours. Afterwards, experiments were repeated with other pollutants – butanol and toluene. The inlet pollutant's concentration range was 535 ± 23 mg/m^3.

Upon completing experiments with wood chips, the biofilter was packing materiald with another packing material of a wood chip and zeolite mixture. Afterward, the experiments were repeated using a mixture of wood chips and foam cubes, and a combination of wood chips, zeolite granules and foam cubes (Fig. 2).

With the aim to determine the dependence of packing material treatment efficiency on a packing material layer height, the concentrations of pollutants were measured before and after each module. To determine the concentrations of pollutants, air samples were taken in special sampling places and each measurement was repeated 3 times.

An air sample from the air duct was sucked through a stainless steel tube (d = 5 mm, l = 30 cm) into a clean gas pipette of 0.25 l at a rate of 0.25 l/min. Sucking was done for 5 minutes. Upon sucking completion, the pipette's ends were, via silicone hoses, tightly stopped with glass plugs and the hoses were additionally tightened with Mohr's pinchcocks. The samples were chromatographically analysed on the same day (Determination of..., 2006).

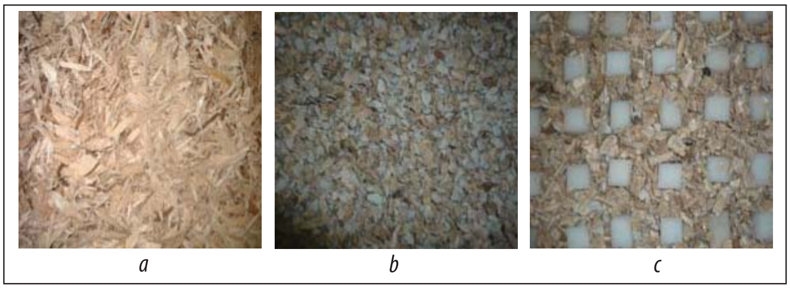

Fig. 2. Biofilter packing materials: a) mixture of wood chips and barks, b) mixture of wood chips, barks and zeolite granules, c) mixture of wood chips, barks, zeolite granules and foam cubes

The concentration of pollutants was determined with a SRI 8610 gas chromatographer with a flameionization detector (FID). Column characteristics: material – steel "Supelcoport", length 6.1 cm, inner diameter 0.32 cm, filled with diatomite and 10% SP-1000 matrix 80/100. The chromatographer sets the following parameters of the analysis process: nitrogen velocity 30 ml/min, hydrogen gas velocity 30 ml/min, air rate 200 ml/min, column thermostat temperature 100 ± 2 °C, vaporizer temperature 200 ± 5 °C, detector temperature 200 ± 5 °C.

Results and discussion

When the device is supplied with the air containing higher concentrations (around 500 mg/m^3) of pollutants, part of the pollutants (around 20%) is adsorbed in the pores of zeolite granules. The treatment efficiency, using the biofilter without zeolite unit, reached up 78 ± 0.8%.

The experimental results showed that the best sorption properties were characteristic of the packing material composed of a mixture of wood chips, barks, zeolite granules and foam cubes. When using this packing material and passing acetone vapour-polluted air through the device at the rate of 0.1–0.2 m/s, a high treatment efficiency (98 ± 1%) of the biofilter with the adsorbing layer of zeolite granules was achieved (Fig. 3).

The higher treatment efficiency of the biofilter was predetermined by the physical properties of packing materials used during experiments. Zeolite has by a porous structure and a large conditional surface air (144 m^2/g), therefore part of a pollutant is adsorbed on the packing material surface. In order to enlarge the conditional surface area of the packing material, a mixture of synthetic and natural packing materials, composed of peat and perlite, is often applied for biological air treatment. Using these packing materials at the 1000 mg/m^3 concentration of the pollutant supplied to the device, the treatment efficiency of the biofilter reaches about 83% (Iranpour et al., 2005). An artificial introduction of microorganisms is required when applying synthetic packing materials. In the meantime, upon mixing zeolite granules and foam cubes with wood chips, favourable conditions for natural development of bacteria of the genus *Pseudomonas* are created (Tekorienė, Lugauskas, 2001; Converti et al., 1997).

Destruction of organic compounds is accelerated due to enhanced properties of humidity sorption upon supplementing the packing material with foam cubes. Foam adsorbs humidity well due to its porous structure, low density (20 kg/m^3) and a large conditional surface area (375 m^2/g). After introducing foam cubes into wood chips, barks and ZeoVit sorbent, the packing material's humidity increases from 45 ± 0.5 to 60 ± 0.6%. After the packing material's humidity changes, the biofilm becomes thicker, which results in an increased air treatment efficiency of the biofilter. The biofilter's treatment efficiency upon humidifying air polluted with acetone vapour supplied to the biofilter also increases from 82 ± 0.8 up to 95 ± 1%. The inlet concentration of the pollutant reaches 535 ± 23 mg/m^3. The air humidification system is highly efficient when the biofilter uses synthetic packing materials characterized by a high porosity (up to 91%) and composed of pearlite granules or propylene rings (Jin et al., 2007).

Upon completing the experiments, the dependence of biofilter treatment efficiency on the type of the pollutant supplied to the device was determined. As data in Fig. 4 show, the highest efficiency (97 ± 1%) was achieved when microorganisms decomposed acetone. Acetone mixes well with water and is completely soluble in it, so acetone vapour is better absorbed on the biofilm formed on a packing material surface. When the device was supplied with toluene vapour with the initial concentration of 305 ± 30 mg/m^3, the biofilter treatment efficiency reached 81 ± 0.8%. In the meantime, as determined by Spanish researchers, toluene treatment efficiency reached 79 ± 0.8% when treating air with a packing material composed of peat (Hornos et al., 2007).

Compared to other pollutants, the lowest treatment efficiency of the biofilter was recorded when treating toluene-polluted air. Toluene is a hydrophobic compound with a

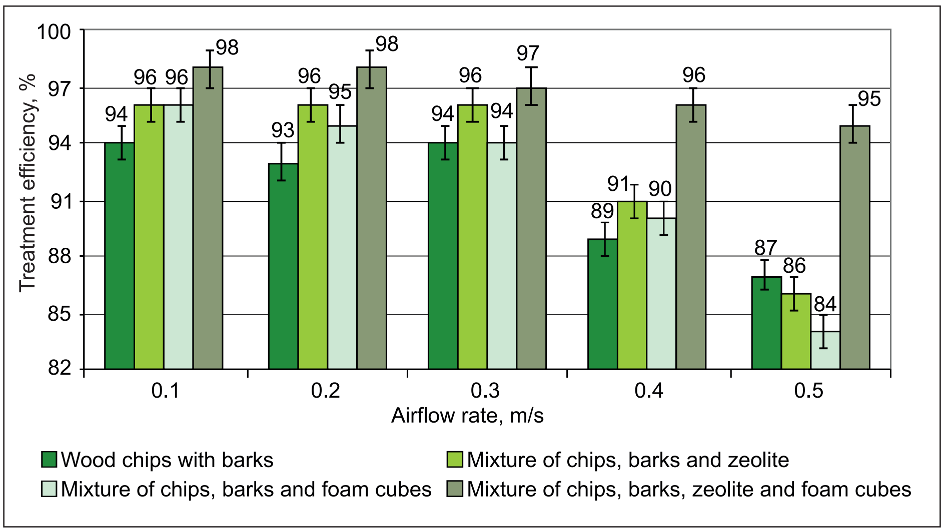

Fig. 3. Dependence of treatment efficiency of air polluted with acetone vapour on the type of biofilter packing material and the rate of fed airflow

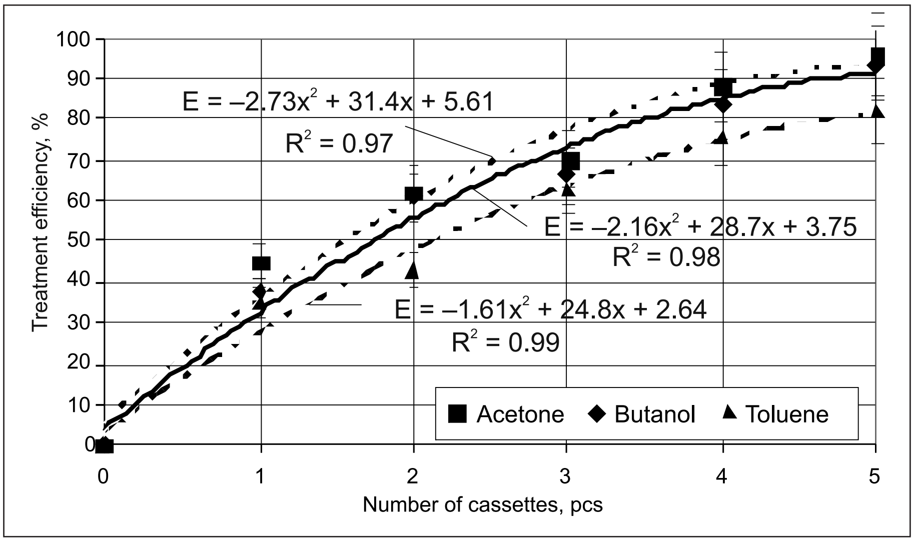

Fig. 4. Dependence of biofilter treatment efficiency on the type of pollutant

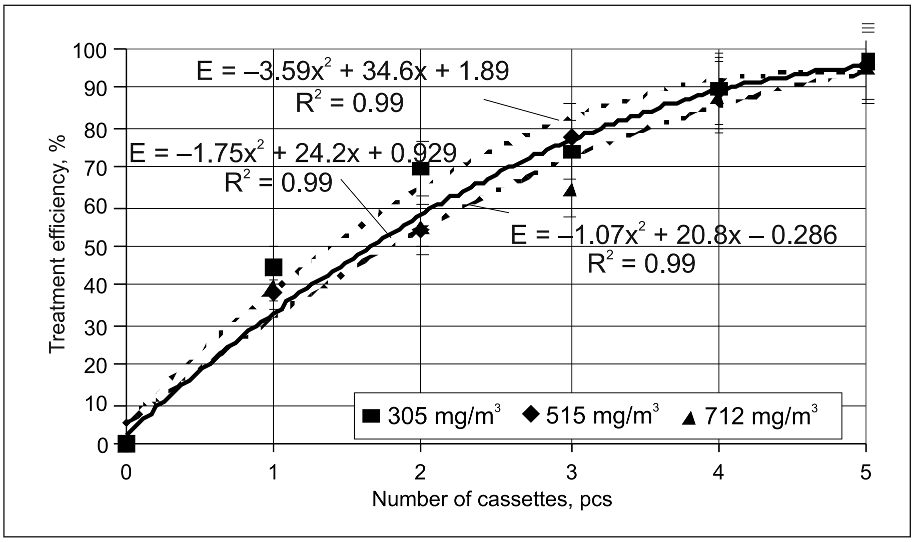

Fig. 5. Dependence of biofilter treatment efficiency on the initial concentration of acetone vapour

water-solubility of 0.53 g/l, thus it is worse adsorbed on the biofilm. The greatest decrease in pollutant concentration was recorded after the packing material's first layer from the bottom, composed of a mixture of wood chips, barks, zeolite granules and foam cubes. After this layer, acetone concentration decreased from 305.0 to 167.8 ± 17.0 mg/m^3. Such a decrease in acetone concentration is predetermined by the biggest pollutant load on the first layer of the packing material (Converti et al., 1997). Therefore, it can be concluded that the biofilm in this layer is thickest.

Acetone is best decomposed at a lower initial concentration of the pollutant. When the initial acetone vapour concentration is 305 ± 30 mg/m^3, the biofilter treatment efficiency reached 97 ± 0.9%. Upon increasing the initial pollutant concentration to 712 ± 45 mg/m^3, the treatment efficiency of biofilters fell to 95 ± 0.9% (Fig. 5). Organic compounds are adsorbed in the zeolite layer. Researchers from Louisiana State used activated carbon for the biofiltration of acetone and toluene vapours. The research results showed that the biofilter treatment efficiency reached up to 98 ± 1% when using a packing material with good sorption properties for biological air treatment (Li, Moe, 2005; Iranpour et al. 2005). Replacement of an activated carbon packing material by natural zeolite with good sorption properties reduces the operational costs of biofiltration.

Compared to other methods, the biological method used to clean air from volatile organic compounds is most cost-effective and efficient. As established by German researchers, the biofiltration of organic compounds, such as acetone or butanol, generated in large quantities in industries, reduces the concentration of their vapour from 900 to 15 mg/m^3 (Jantschak et al., 2004).

Our research results show that with the vapour concentration of the pollutant fed to the device packing materiald with wood chips, zeolite granules and foam cubes increasing, the biofilter's treatment efficiency decreases. When air polluted with acetone vapour at a concentration of 305 ± 30 mg/m^3 is supplied to a biological air treatment device, the efficiency of the device reaches 97 ± 0.8%. Upon increasing the initial pollutant concentration to 712 ± 45 mg/m^3, the efficiency of biofilters fell to 95 ± 0.9%. A better performance of the biofilter is achieved at lower initial concentrations of pollutant vapour. Upon considerably increasing the concentration of pollutant vapour passed through the device, microorganisms did not manage to fully decompose pollutants of a higher concentration (712 ± 45 mg/m^3). Found 20 ± 4% of organic compounds are decomposed in the adsorbing layer of zeolite and adsorption unit. Therefore, even upon increasing the pollutant's concentration 2.3 times, a high efficiency of the device (95 ± 0.9%) was maintained.

CONCLUSIONS

1. The highest efficiency was treatment device's obtained using an activated packing material composed of wood chips, barks, zeolite and foam cubes. The treatment efficiency reached up to 98 ± 1% at the airflow rate of 0.1 m/s fed to the biofilter and the initial acetone vapour concentration of 305 ± 30 mg/m^3.

2. Acetone was decomposed best in the biofilter. After the packing material's five layers the concentration of acetone vapour decreased by 98 ± 1%. The lowest treatment efficiency (81%) was obtained when air was cleaned from toluene – a hydrophobic organic compound poorly soluble in water.

3. The biofilter's high treatment efficiency was achieved when the device was supplied with air polluted with lower concentration vapours. The device's high treatment efficiency (95%) was attained when supplying it with polluted air at 305 ± 30 mg/m^3; 20 ± 4% of organic compounds were adsorbed in the zeolite layer before the biofilter.

4. With increasing the pollutant filtration time, the biofilter's efficiency also increases. When the inlet concentration of acetone vapors reaches 305 ± 30 mg/m^3, upon extending the time of filtration from 1.7 to 7.0 seconds, the device's efficiency increased from 72 ± 0.7 to 98 ± 1%. The high efficiency of the biofilter at a rather short duration of the polluted air filtration is predetermined by porous zeolite granules with a large conditional surface area.

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Alvydas Zagorskis, Pranas Baltrėnas

BIOFILTRO SU ADSORBUOJANČIU CEOLITO SLUOKSNIU ORO VALYMO EFEKTYVUMO TYRIMAI

Santrauka

Biologinio oro valymo metodas pagrįstas organinių junginių biologine destrukcija naudojant tam tikrus mikroorganizmus. Metodas nesudėtingas ir gali būti taikomas daugelyje pramonės šakų.

Eksperimentiniams tyrimams atlikti naudotas oro valymo biofiltras su adsorbuojančiu ceolito sluoksniu. Didžiausias oro valymo efektyvumas gautas dėl aktyvintos įkrovos, sudarytos iš medienos skiedrų, žievių, ceolito ir porolono kubelių mišinio. Esant į biofiltrą tiekiamo oro srauto greičiui 0,1 m/s ir pradinei acetono garų koncentracijai 305 ± 30 mg/m^3, įrenginio valymo efektyvumas siekė iki 98 ± 1 %. Didelis – 97 ± 0,9 % – biofiltro oro valymo efektyvumas pasiektas į filtrą tiekiant didesnės – 712 ± 45 mg/m^3 – koncentracijos teršalų garais užterštą orą.

Siekiant pailginti įkrovos tarnavimo laiką siūloma orą valyti naudojant eglės žievių ir medienos skiedrų, ceolito granulių ir porolono kubelių mišinį. Tyrimai parodė, jog biologiniam oro valymui naudojant šias įkrovas biofiltro valymo efektyvumas pakinta nežymiai, kartu pailginamas įkrovos tarnavimo laikas. Prieš biofiltrą įrengta kamera su adsorbuojančiu ceolito sluoksniu sumažina į biofiltrą tiekiamų teršalų garų koncentraciją iki 20 ± 4 %.

Raktažodžiai: biofiltras, biodestrukcija, acetonas, mikroorganizmai