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Formaldehyde Removal from the Air by Biofilter Packed with Reed Charge

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Abstract

Yearly almost 15 thousand tons of volatile organic compounds (VOCs) are being emitted in Lithuania by various industries. To reduce these releases into the air biofiltration, using particular cultures of microorganisms, is one of the most perspective air treatment method. The possibility to implement biofilter packed with reed charge reducing these amounts and cleaning VOCs and odors is being assessed in the article. It was analysed removal efficiency of biofilter packed with reed charge, which measured porosity was equal to 80%. The efficiency of biofilter was measured treating formaldehyde. The results of experiment showed, that the highest overall removal efficiency E=91.68% treating formaldehyde polluted air stream up to 20 mg/m^3 using the upright reed charge decomposition. Therefore, the filter efficiency was tested depending on the number of its charge layers height and on different injected air stream rate.

Keywords: biofilter; biofiltration; volatile organic compounds; formaldehyde; common reed.

1. Introduction

Formaldehyde is a common intermediate product of the oxidation of most Volatile Organic Compounds (VOCs). It plays an important role in urban atmospheric chemistry and ozone formation [1]. Formaldehyde can be directly emitted from incomplete combustion processes, such as combustion engines and biomass burning, or produced by photooxidation of hydrocarbons. Small amounts of formaldehyde can also be emitted directly from vegetation [2]. Formaldehyde is a known carcinogen [3], [4] exposure to high levels of ambient formaldehyde is detrimental to human health and to the ecosystem.

In 2012 about 29.9 tons of formaldehyde were emitted in Lithuania by various industries [5]. To reduce these releases into the air, biofiltration method may be applied. Control of VOCs from a variety of industrial and public sector sources such as chemical manufacturing, industrial waste and residential wastewater treatment plants, waste oil recycling facilities, composting facilities, and coating operations is one of the widest applicabilities of this technology [6].

In practice, construction of biofilters is not complicated; moreover, their capital and maintenance costs are low and the period of service is enough long (up to 10 years). These filters have a rather large area of biomedium with 40–60% porosity, which is full of microorganisms. All this helps to achieve a high air cleaning efficiency (up to 90–99%). Depending on the size of the filter, filters may be used in the premises of an enterprise or within its territory, i.e. outside. Sure, use of such filters is easy during the warm period or in the closed premises where the ambient temperature is more or less constant (or in the range of several degrees). Depending on the nature of production and amount of the emitted amount of pollutants, biofilters assembled at the plants need a rather large area (from 10 to 2000 sq m) and may be used in the cold period (later autumn, winter and early spring). Biofilters are relevant for those countries (including Lithuania which is situated in a temperate zone) that have both warm and cold periods, i.e. when temperature changes from below to above zero and vice versa [7–9].

According to the scientist J. Liang, packing material is a crucial component of a biofilters as it is the microbial population's habitat. For microorganisms the charge serves as a substratum predetermining growth of their population; besides, the charge sorbs pollutants, ensures continuous contact of pollutants with its biologically activated area, provides microorganisms with biogenic elements, keep constant regimes of humidity, temperature, pH, etc. Organic materials such as compost, peat, soil are historically used as filter media, though in recent years synthetic materials have proven to be effective media as well when combined proportionately with organic material [6], [11].

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The aim of the paper is to access the efficiency of biofilter, packed with reed charge, by varying filter parameters (charge height and airflow speed) and initial concentrations (up to 100 mg/m³) of formaldehyde.

2. Methodology

2.1. Reeds as sorbents

The aim of this study was to investigate the ability of reeds (L. *Phragmites australis*) growing near the lake sides to absorb formaldehyde from polluted air stream when it flows through filters filled with this material. For the efficient use of filter media for air treatment, it is essential to focus on studies on sorbing filter materails and the necessary filtration conditions. The natural sorbents capacity to sorb volatile organic compounds must be examined before they are used in biofilter.

Among the biological materials, reed is a widespread, dominant plant species in many aquatic ecosystems [12]. The plant grows up to 100–400 cm. It is is a hydrophytic species with typical habitats of fresh and brackish swamps, riverbanks and lakesides. However, reeds can also adapt to adverse terrestrial habitats; various ecotypes exhibiting genetic differences have evolved resistance to drought, salinity and low temperatures [13].

The reed plant is reported to contain high amount of lignin and cellulose [14]. Lignin and cellulose are known to absorb many heavy metal ions from aqueous solution [15]. It can also withstand extreme environmental conditions, i.e. the presence of toxic heavy metal conditions, i.e. the presence of toxic heavy metal contaminats, such as Zn, Pb and Cd [16–17]. Considering the fact that *Phragmites Australis* is resistant to polluted environment and have the capability to accumulate heavy metal in its body, plant biomass itself may also be used to remove heavy metals by harnessing its natural properties.

Use of the common reeds as naturally sorption charge for the VOC removal from the polluted air, can be possible on a global scale, because common reeds are widespread worldwide distribution from the subtropical to the tropical climate zones. This plant consists up to 1220 t dry mass per year in Lithuania. The economic price of one tone dry reed mass is equal about 200 Lt (or 80 $). For example, it would be used 0.03 t mass charge in the experimental investigation filter. The price of such charge would be equal to 6 LT (or 2.39 $).

For the experiment described in this paper, an investigated material was common reed. Reeds were taken from Elektrėnai Lagoon, in Lithuania. Long reed stems were collected in autumn, dry up and cut into pieces before placing them into the biofilter column in the laboratory.

2.2. Experimental setup

Using the developed biofilter with reed charge the experimental tests were carried out at the Department of Environment Protection of Vilnius Gediminas Technical University. The biofilter (0.5×0.48×2.0 m) with biologically activated reed charge contains five separate layers of biomedium, which mutually do not press each other, are separated by meshes and ensure even distribution of air flow. When purifying air from volatile compounds of organic nature, flow of polluted air is blown through all five layers of biomedia by means of ventilator. There are dampers installed with control handles in the inlet and outlet ducts of the filter to adjust flow velocity (0.02 to 0.10 m/s). In order to increase amount of polluted air, inlet air duct has funnel shape at the front end. Purified air is exhausted through the flexible duct from the filter. Temperature of 28 ºC is maintained in the filter charge, so the medium is heated by two heating elements installed at the side walls of the filter.

Prior starting the biological air treatment process, the microorganisms activation process, which continues about two weeks, were carried out. In activation process, VOCs 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 reed. 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 reed samples at 100–105 ºC until constant weight was obtained. The necessary temperature 28 ºC in the filter was achieved by heating biomedium at the side walls of the filter with the help of two heating elements.

Experimental tests were performed in the biofilter charge with neutral pH=7. To maintain this neutral pH value the charge was introduced with sodium (Na_2HPO_4) and potassium phosphate (KH_2PO_4) solutions.

For microbial growth there are three essential elements: carbon (C), nitrogen (N), and phosphorus (P). Prior to starting the equipment and when operating it, up to 0,42 kg of solution of mineral salts (KH_2PO_4) – 1 g, KCl – 0.5 g, $MgSO_4{\cdot}7H_2O$ – 0.5 g, $FeSO_4{\cdot}7H_2O$ – 0.1 g, NaN O_3– 0.91) 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. Therefore, the prepared solution of nutrients was poured into the water tank and sprinkled together with water above each biomedium layer.

During the experimental research it was used measuring device “TESTO-452” with thermopair to measure the air flow rate.

To evaluate the aerodynamic resistance of the charge, measurements of dynamic pressure before each charge layer by means of differential pressure meter “DSM-1” were performed repeating each measurement five times.

During the experimental research it was revealed the efficiency of the filter by changing initial concentrations of formaldehyde, air flow speed and the height of charge layers. To compare pollutant biodegradation in the activated reed charge, six different concentrations up to 100 mg/m³ were taken approximately every 15–20 mg/m³ [18–20].

Different concentrations of organic substances were obtained by heating them in a pot on a regulated electric range. Temperature of the airflow injected into the equipment varied in the range of 20–55 °C, therefore the temperature regime maintained in the charge had to be increased by several degrees. Air samples before and after the filter and after each layer were taken at measurement points by using the glass-type pickup tubes (Ø 4.0±0.1 mm, length 7.0±0.01 m) filled with activated coco carbon (0.3–0.85 mm) produced by the SKC company and the personal sampler Airchek 224-PCXR8 for 15 min at 0.2 l/min speed.

Concentration of compounds under investigation in the air samples was determined by chromatography. The gas chromatograph Hewlett Packard Model 5890 having sensitivity of the flame ionisation sensor of 4·10-9 mg/s, glass column (Ø 3.0±0.1 mm, length 2.0±0.01 m) filled with the chromosorb WHP (0.18–0.15 mm) and 10% OV-101 was used. Temperatures were as follows: the column temperature was 90 °C, the detector temperature was 250 °C, the evaporator temperature was 200 °C. After performing the chromatographic analysis, the arithmetic mean value of the organic compound reed area was calculated based on three measurements of the sample. Using the calibration curve as the basis, the amount (in mg) of the substance analysed was determined in the smaller and larger sections of the pickup tube under investigation. After determining concentrations of organic substances under investigations by chromatographic analysis, efficiency of the biologic air purifier was calculated.

During the experiment the room temperature was as follows: air temperature 18–20 °C, atmospheric pressure 749–751 mm Hg column and humidity 68% [21].

3. Results

The performed experimental tests had showed that a filtering layer of biocharge can filtrate such toxic substances as formaldehyde. Aerobic microorganisms (mesophilic bacteria), that live under certain conditions in the charge of reeds, which are maintained by the filter, consume formaldehyde that is dissolved in water and regenerate the sorbent at the same time.

During the experimental testing, different initial concentrations (up to 100 mg/m³) of volatile organic compounds (formaldehyde) were injected into the biofilter and different main parameters of the filter (charge height and airflow speed). Tests were performed in the reed charge with neutral pH=7. Spontaneous microorganism groups were cultivated in the charge. Science researcher Gaudin knews, that every material generated a basic pH, whereas a neutral pH is an optimum condition for bacterial growth. 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 [22–23].

In the first experiment, the filter efficiency was tested depending on the number of its charge layers. The height of one biomedia layer is 0.15 m. 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 biomedia and higher concentration microorganisms. When the number of layers was increased up to five and the biomedia height was equal to 0.75 m, the efficiency of air cleaning at that same initial concentration was higher. For example, with the initial concentrations of pollutants (formaldehyde) amounting 96 mg/m^3 the air cleaning efficiency after the air passed one layer was 61.1%, and after passing five layers it increased by 15% and reached 71.9%.

Results of formaldehyde removal efficiency depending on the layer height are presented in Figure 1.

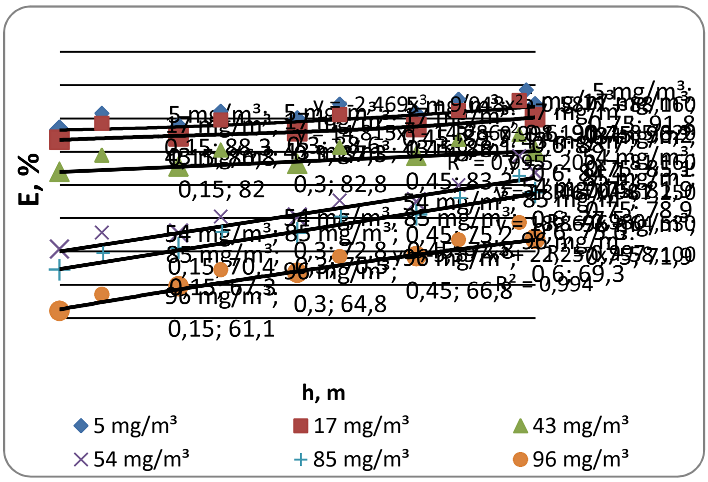

Fig. 1. The removal efficiency of formaldehyde according to the layer height of the charge

As it can be seen from the Figure 3.1 injecting the air with lower concentration (from 5 to 17 mg/m^3), the air cleaning efficiency after one layer and after five layers differed by 3–5%. For example, the efficiency of air cleaning of formaldehyde with the initial concentration of 5 mg/m^3 after one charge layer was 88.3%, after five layers it was 91.8%. With the increasing initial pollutant concentrations, biofiltration efficiency change after one and five layers reaches 4%. The cane charge (as a porous material) used in device shows the such good results of the air cleaning. It deters the emitted pollutant quite good and the micro-organisms decompose that pollutant after detention. The best contact time between pollutant and activated bio-charge part (bio-layer) is 1–4 seconds. Moreover, the efficiency of air cleaning of formaldehyde with the initial concentration of 54 mg/m^3 after one charge layer was 70.4%, after five layers it was 81.90%. With the increasing initial pollutant concentrations, biofiltration efficiency change after one and five layers reaches 14%. The biggest change in efficiency is noticeable at higher values of initial concentration (e.g. starting from 54 mg/m^3), but the overall removal efficiency at such concentrations is noticeably lower. The removal efficiency of formaldehyde according to the layer height of the reed charge is highest injecting the air with lowest concentration (5 mg/m^3) threw 5 layers of the charge.

After the first experiment, it was determined that with the increasing charge height (from 0.15 to 0.75 m), the area of surface in contact with pollutants became larger and efficiency (in %) of air cleaning became much better.

Next experiment involved the determination of removal efficiency according to the air stream flow rate. During this experiment the air polluted with formaldehyde was injected at the speed ranging from 0.02 up to 0.1 m/s. The results of this experiment are shown in figure 2.

Figure 2 shows the results when measuring the efficiency of reed charge, by the upright reed decomposition and which has porosity value of 80%. At the pH=7 the filter efficiency of 91.30 % is achieved when the speed of formaldehyde with the initial concentration of 3 mg/m^3 and flow rate of 0.02 m/s. However, when the speed of the same concentration formaldehyde is increased up to 0.10 m/s, the filter efficiency decreases down to 87%. Accordingly, when the initial concentration of formaldehyde is up to 26 mg/m^3, the air to be clean may be injected at the speed of 0.06 m/s and even at a higher speed, in which case the efficiency of air cleaning is 87.88%. If the speed of the airflow passing the filter is increased up to 0.1 m/s without changing the above mentioned test conditions (the initial pollutant concentration 94 mg/m^3, biofiltration efficiency goes down to 59.2%. The 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. The such obviously decent treatment of contaminants such as formaldehyde, shows that in a filter charge,including the spontaneous microorganisms (*Methylomonas* and *Methylosinus*) that have methane-oxygenase ferment. Microorganisms, those have this ferment, catalyze the formaldehyde to the final products: formic acid, water and CO_2.

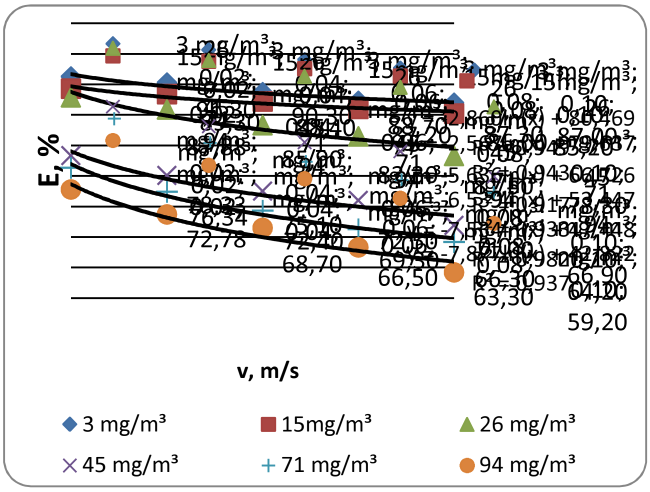

Fig. 2. The removal efficiency of formaldehyde according to the air stream flow

The overall removal efficiency of formaldehyde is shown in Figure 3. This figure shows the overall removal efficiency of formaldehyde for air stream when using biofilter packed reed charge composed by the upright composition .The measured porosity of this charge was equal to 80%. All concentrations were measured three times and were estimated an average, which was used in graphics. As it can be seen from this figure, the biofilter is effective at treating air stream from low concentrations of formaldehyde. The filter efficiency is varied between 71.82% and 91.68%. The highest removal efficiency up to 91.68% was determined when treating the polluted air stream up to 15 mg/m^3. The lowest treating efficiency down to 71.82% was determined when treating the polluted stream up to 90 mg/m^3.

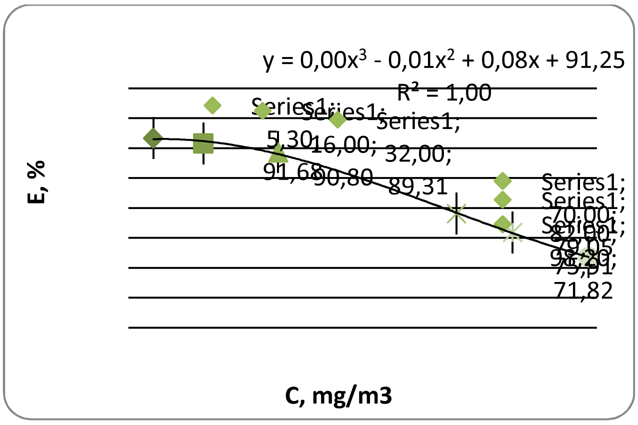

Fig. 3. Overall formaldehyde removal efficiency

According to the experimental tests, the efficiency of air treatment treating formaldehyde decreases when the concentrations of pollutants increases. The efficiency of biological air treatment of these constituents are above 90% for low concentrations of contaminants (<30 mg/m^3). Hence, after the assessment of formaldehyde chemical nature and in order to ensure the effective application of the charge in air treatment process, it is recommended to apply reed charge in the biofilter.

4. Conclusions

1. The paper analyses the ability to use reeds (*Phragmites australis*) as biofilter filler, to treat air, polluted with volatile organic compounds such as formaldehyde. Reeds are efficiency and inexpensive material, that can be widely used as biocharge for the VOC treatment from ambient air. Filler are quite efficient biofilter media (E = 91.68%) for formaldehyde removal from polluted air stream. The use of common reeds are possible due to their worldwide distribution, low cost and considerable quantities.
2. Analysis of biofilter performance, when pH value was kept at neutral (pH = 7), showed that the efficiency of biofilter depends on biomedia layer number and their height. Higher number of layers and height influence better efficiency of contaminated air treatment. Formaldehyde removal efficiency at initial concentration of 5 mg/m^3 after one charge layer of 15 cm was equal to E = 88.3%, while passed through 5 layers of 75 cm height, the efficiency reached E=91.8%. These results resemble using upright reed charge decomposition with the porosity 80%.
3. Performed experimental investigations with different air flow rate, while pH = 7, it is ascertained, that lower velocities of contaminated air stream flow rate influence the effectiveness of air treatment e.g. formaldehyde treatment at air flow rate 0.02 m/s the removal efficiency initial concentration C = 3 mg/m³ is equal to E = 91.3%. When the velocity was increased up to 0.10 m/s, the efficiency declined to 87.88%. These results resemble using upright reed charge decomposition with the porosity 80%.
4. The results of analyses show, that the efficiency of biological air treatment vary depending on primary pollutants concentrations. The highest removal efficiency up to 91.68% was determined when treating the polluted air stream concentration was up to 15 mg/m^3. The lowest treating efficiency down to 71.82% was determined when treating the polluted stream with concentration up to 90 mg/m$^{3.}$
5. The results obtained in this experimental work can be used in designing equipment for the air, contaminated with volatile organic compounds, treatment in various industry companies.

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