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EFFECTIVENESS INVESTIGATIONS OF CLEANING AIR FROM AMMONIA BY APPLYING A PLATE BIOFILTER WITH A SAWDUST CHARGE

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Abstract. Air treatment biotechnologies are the most cost-effective and eco-friendly means of reducing the atmospheric emissions of ammonia and other odoriferous substances such as xylene, hydrogen sulphide, acetone, butanol, etc. The main shortcomings of the currently used biofilters are high aerodynamic resistance of a charge, complicated maintenance of humidity and operating temperature in a charge, obstruction of a biocharge with a mass of microorganisms and a big space required for biofilters. It is necessary to develop new technological solutions for rectifying the afore-mentioned shortcomings. The aim of this research is to investigate the effectiveness of a plate-type biofilter with a capillary charge humidification system. The investigation covered identification of the dependence of biofilter's effectiveness on time, supplied pollutant concentration and velocity in a charge. As determined during the investigation, biofilter's effectiveness became stable after 35 days of operation. When the velocity of airflow passed through the biofilter was 0.04 m/s, biofilter's effectiveness reached 79 %.

Keywords: biotechnologies, ammonia, plate, biofilter.

1. Introduction

Increasingly stringent requirements with regard to pollutant emissions encourage search for, on the basis of research, effective and cost-efficient ways of air pollution control and prevention (George 2001). Expensive and low-efficiency usual air treatment technologies, such as activated carbon filters, absorbents, chemical scrubbers and similar, are currently being used. Application of physical and chemical air treatment technologies leads to the accumulation of secondary pollution products. Chemical scrubbers are often used for minimising pollutant emissions. However, their shortcoming lies in the fact that they require chemical substances, such as sodium hypochlorite or sodium hydroxide, water supply and huge operational costs and also generate precipitate (Norbertus 2006).

Biological degradation of pollutants have been successfully applied worldwide for cleaning a wide spectrum of pollutants including VOCs, ammonia, H_2S, which are released by industrial and agricultural air pollution sources. Microorganisms present in a charge decompose (i.e. oxidise) airborne volatile organic compounds (VOCs), inorganic gases and aerosols, which are the components of odoriferous air. The process of biological oxidation results in the formation of water, carbon dioxide and microbe biomass (Busca 2003; Baltrėnas 2007).

The shortcoming of the currently used biofilters are high aerodynamic resistance of a charge, complicated system of humidity, likely obstruction of a biocharge with a mass of microorganisms, short service life of a biocharge and a big space required for biofilters (Baltrėnas 2007; Baltrėnas 2009).

Research on air cleaning from high concentration ammonia was done by US researcher Nam Jin Kim in 2000. Another research was devoted to the effectiveness of air cleaning from ammonia using four biocharges with different properties (Hirai 2001).

The aim of this research is to determine, by using a plate-type biofilter, the effectiveness of ammonia gas removal from polluted airflows; and, by using a capillary charge system, to determine the dependences of air treatment effectiveness on airflow velocity, pollutant filtration time and initial ammonia concentration.

The effectiveness of biological air treatment largely depends on humidification systems installed in biofilters. The optimum humidity of a charge is 60–80 %. Charge in the currently applied biofilters is humidified with humidification sprayers arranged above it to which water is supplied by a pump from a water tank. Application of such a humidification system requires much electric power, leads to the emergence of anaerobic areas inside a filtering layer and can cause biomass leaching out of the charge, while this reduces air treatment effectiveness of biofilters. If power supply is interrupted or a technological process is stopped a charge is not humidified and therefore it can get too dry and crack.

As known from the laws of physics, when a liquid interacts with the walls of a solid body, the forces of surface stress try to raise the level of the liquid. The column pressure of liquid ascended by the walls of a solid body is set off by the pressure directed upwards which is created by curved surface stress. Thus, when impacted by the forces of surface stress, liquid is flowing along capillaries. In physics such a phenomenon is known as capillarity and can be applied in an air treatment biofilter for the humidification of a charge.

2. Research methods

An experimental plate-type biofilter was designed and produced for this research (Fig. 1). The biofilter has a plastic body with a length of 280 mm, width of 230 mm and height of 260 mm. Air supply and air release pipes, with their diameter reaching 135 mm, are connected to the biofilter. A tray, filled with ammonia solution, is used to create a source of pollution. Ammonia reaches the device while evaporating at a temperature of 20 °C from the tray with a diameter of 100 mm and depth of 10 mm. The air pipes have openings with a diameter of 10 mm, which are intended for measuring airflow velocity and pressure and identifying pollutant concentration. The supply air pipe is fitted up with a ventilator. Airflow velocity is regulated with a valve from 0.05 m/s to 1.5 m/s.

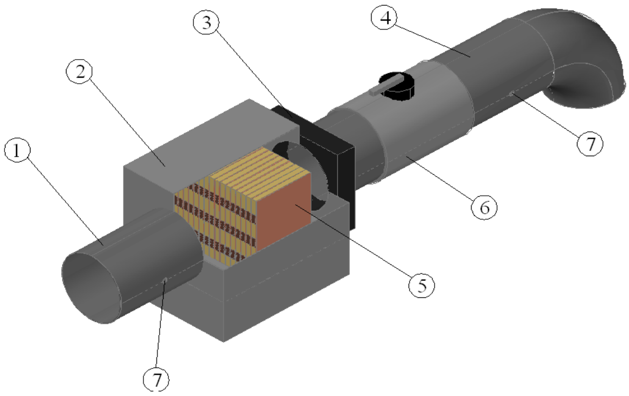

Fig 1. Cassette biofilter, partial section: 1 – cleaned air release pipe; 2 – biofilter body; 3 – ventilator; 4 – polluted air supply pipe; 5 – biocharge; 6 – valve; 7 – measurement openings

Biofilter's charge (Fig. 2) is composed of nineteen capillary plates which maintain humidity. Plate thickness reaches 2 mm, and the plates are pasted with sawdust.

The bottom part of the humidifying plates was immersed in water. Plate immersion depth reached 60 mm. The biofilter was filled with 3 litres of water. Water from the tanks ascends via capillaries thus humidifying the entire plate of a biocharge. The total area of the plate contact with polluted air is 0.831 m^2. While flowing through the charge, vapour-saturated air eliminates humidity and reduces charge's humidity. However, the process of biodegradation at the same time transforms organic compounds into carbon dioxide (CO_2) and water and partially restores the amount of humidity. Degradation of 1 kg of hydrocarbon generates 1.5 of water. Quite frequently this amount of water is insufficient and the charge, therefore, has to be watered additionally. To ensure an effective process of pollutant biodegradation charge's humidity has to reach 40–70 % (Jankevičius and Liužinas 2003; Yamamoto *et al.* 2005).

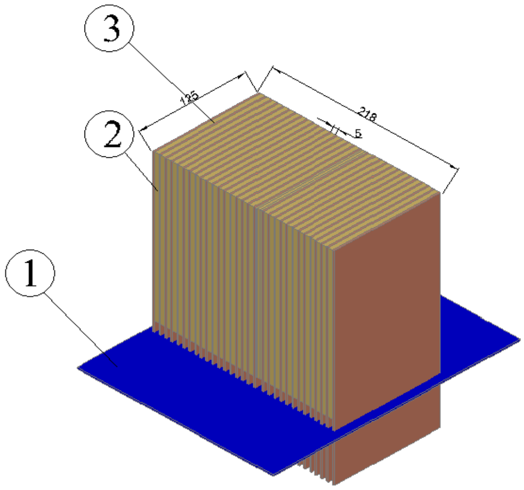

Fig 2. Biofilter's cassette: 1 – water level; 2 – wood charge; 3 – humidifying plates

Airflow velocity, pressure losses and airflow temperature were measured with *Testo 400*, an instrument of the German manufacturer Testo, by connecting a thermoelement or Pitot tube to it. Due to uneven airflow velocity distribution, velocity in an air pipe cross-section was measured at 0.707 and 0.3 (unit parts) from the air pipe wall – 48 mm and 20 mm. The result was recorded when the air flow velocity was stable. Velocity was measured at twelve points. Temperature and pressure losses were recorded at the same points as the airflow velocity. The measurement places of these parameters are presented in Figure 3.

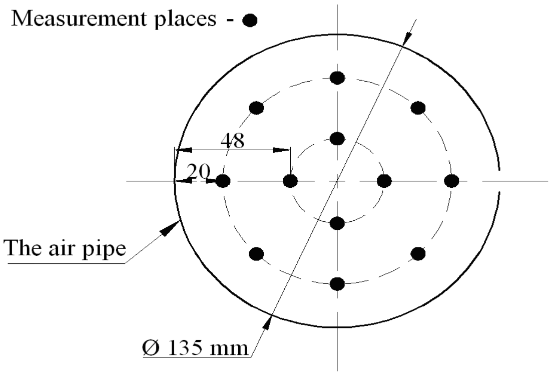

Fig 3. Diagram of airflow velocity, temperature and pressure measurement places in the air pipe

The concentration of ammonia was measured with the instrument *MiniRae – 2000* from the American firm *RaeSystems* whose measurement limits range from 0 to 7 000 mg/m³. The measurement accuracy at pollutant's concentration from 0 to 100 mg/m^3 is 0.1 mg/m^3, while at pollutant's concentration above 100 mg/m^3 – 1 mg/m^3.

The bottom part of biofilter's cassette was immersed in water saturated with biogenic elements. The biogenic elements are a solution of salts consisting 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, distilled water – 1,000 g (Baltrėnas and Vaiškūnaitė 2003). While ascending via plate capillaries, water is continually humidifying the biocharge. Prior to starting the investigation, microorganisms present in the biocharge were activated with ammonia vapour. Activation lasted for 40 days. During acclimatisation airflow velocity in the biocharge reached around 0.04 m/s, and the concentration of the supplied ammonia was gradually increased every 10 days from 50.0 to 250 mg/m^3.

Pollutant concentration was recorded on a daily basis during the investigation. The biofilter operated 3 hours per day. Daily measurements were carried out at airflow velocities in the air pipe of 0.1, 0.25 and 0.5 m/s. Airflow velocity was controlled with a valve. Velocity, temperature and pressure were measured in each operation mode three times.

Prior to measurement a source of pollution was created by filling a tray with 25 % ammonia solution. The tray was placed under the air supply pipe and the ventilator was switched on. Airflow velocity was set with the help of the valve. Airflow velocity was measured in the measurement locations arranged before and after the biofilter. Velocity measurement points are presented in Figure 3. Velocity measurements in the air pipe were followed by temperature and pressure measurements.

Finally, ammonia concentration before and after the biofilter was measured.

Pressure was measured with a dynamic pressure meter *DSM-1.*

3. Results and discussion

Biofilter's air treatment effectiveness was determined by supplying the biofilter with polluted air at 0.04±0.01, 0.1±0.01 and 0.5±0.01 m/s velocity.

Temperature was measured prior to determining ammonia concentration and airflow velocity during the investigation. Air temperature in the air pipe was equal to 18.7±1.0 °C.

Capillary plates raise water upward and thus humidify the biocharge. Throughout the experiment the humidity of capillary plates and biocharge did not change. The humidity of capillary plates was 94.2 %, of sawdust – 63.3 %.

Figure 4 shows ammonia concentrations which were recorded before and after the biofilter as well as air treatment effectiveness when the biofilter is supplied with air at 0.04±0.01 m/s velocity and air yield is equal to 1.43±0.15 l/s. Ammonia concentration was increased every 10 days. Ammonia concentration in the air which was supplied between the first and 10th days varied in the range of 50.0 and 59.6 mg/m^3, between the 11th and 20th days – 100 mg/m^3 and 128 mg/m^3, between the 21st and 30th days – 152 mg/m^3 and 200 mg/m^3 and between the 31st and 40th days of activation – 232 mg/m^3 and 259 mg/m^3. The content of ammonia in the cleaned air varied from 39.7 mg/m^3 to 96.5 mg/m^3. Air treatment effectiveness changed from 9.6 % to 79.1 %, respectively. Air treatment effectiveness increased as bacteria have acclimatised to ammonia in the biocharge, the amount of bacteria enlarged to 10^7 – 10^8 ksv/g (Baltrėnas 2004).

Figure 5 shows ammonia concentration in the air discharged from the device and the dependencies of air treatment effectiveness on supplied pollutant concentration when airflow velocity in the biocharge is equal to 0.04±0.01 m/s. Investigations were carried out at cleaned air yield of 1.43±0.15 l/s. The biocharge and polluted air contact time reached 3.34±0.04 s. When supplied concentration was up to 17.0 mg/m^3, biofilter's air treatment effectiveness reached 100 %, while the effectiveness of 90 % was maintained when the concentration of ammonia vapour supplied to the device was 112.8 mg/m^3. When ammonia concentration in supplied air was above 550 mg/m^3, air treatment effectiveness started decreasing exponentially.

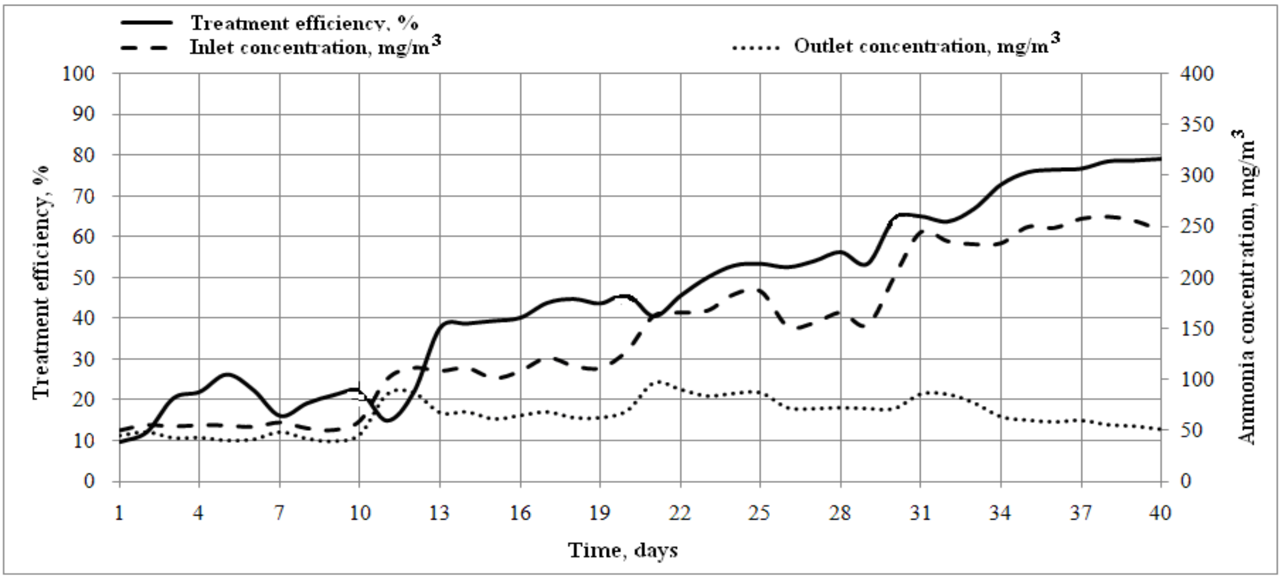

Fig 4. Dependence of air treatment effectiveness on time when airflow velocity in biocharge is equal to 0.04±0.01 m/s

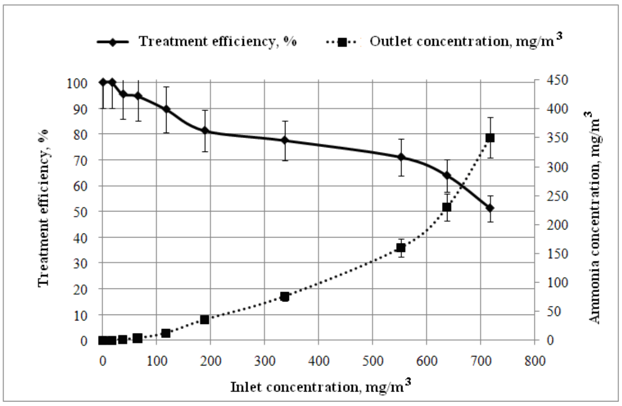

Fig 5. Dependence of air treatment effectiveness on supplied ammonia concentration when airflow velocity in a biocharge is equal to 0.04±0.01 m/s

Figure 6 shows ammonia concentrations in the discharged air and air treatment effectiveness upon increasing airflow velocity to 0.1±0.01 m/s. The time of polluted air contact with biocharge reached 1.34±0.3 s. Air treatment effectiveness considerably decreased as the biofilter cleaned by 2.5 times larger amount of air than in the case of a biocharge with the lowest velocity (0.04±0.01 m/s).

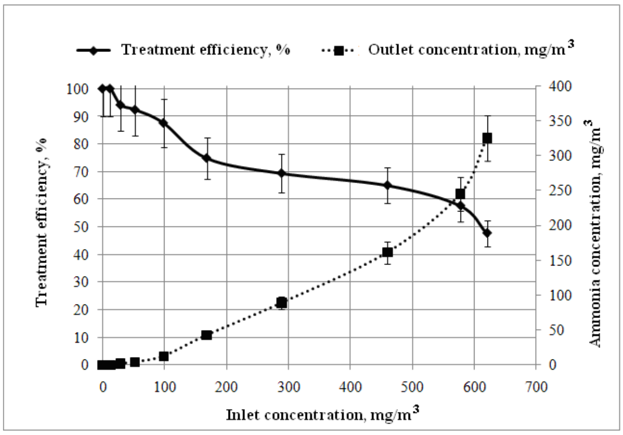

Fig 6. Dependence of air treatment effectiveness on the supplied concentration of ammonia at an airflow velocity in the biocharge of 0.1±0.01 m/s

When the supplied concentration is up to 12.1 mg/m^3, air treatment effectiveness of the biofilter reaches 100 %, while 90 % effectiveness is maintained when pollutant vapour concentration reaches 79.0 mg/m^3. Like in the case of a lower load, when the concentration of ammonia in the supplied air exceeds 550 mg/m^3, air treatment effectiveness starts exponentially falling.

With concentration of ammonia in the supplied air increasing biofilter's air treatment effectiveness was decreasing (Fig. 7). At the highest load of biofilter airflow velocity reaches 0.5±0.01 m/s. The time of polluted air contact with biocharge reached 6.7±0.3 s. When the concentration of ammonia vapour exceeds 100 mg/m^3, biofilter's air treatment effectiveness decreases in a linear manner, while when it exceeds 550 mg/m^3 – air treatment effectiveness starts decreasing exponentially. Air treatment effectiveness was increasing as bacteria present in the biocharge have acclimatised to ammonia, the amount of bacteria increased 10^7 – 10^8 ksv/g (Baltrėnas 2004).

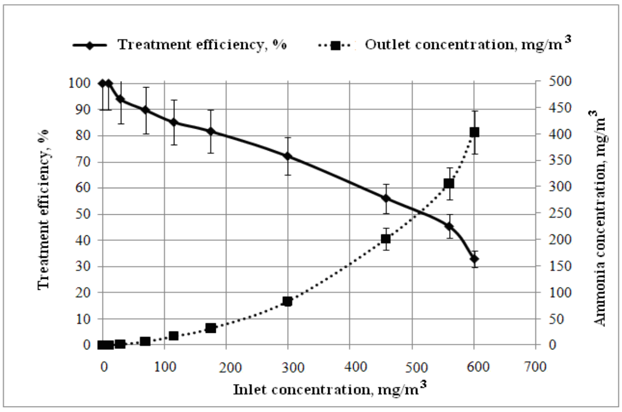

Fig 7. Dependence of air treatment effectiveness on the supplied concentration of ammonia when airflow velocity in the biocharge is 0.5±0.01 m/s

Biofilter's aerodynamic losses did not change throughout the experiment. Aerodynamic losses were measured every five days. Pressure was measured with a dynamic pressure meter *DSM-1*. At low velocities (0.04–0.25 m/s) air resistance is very low and reaches 30 Pa.

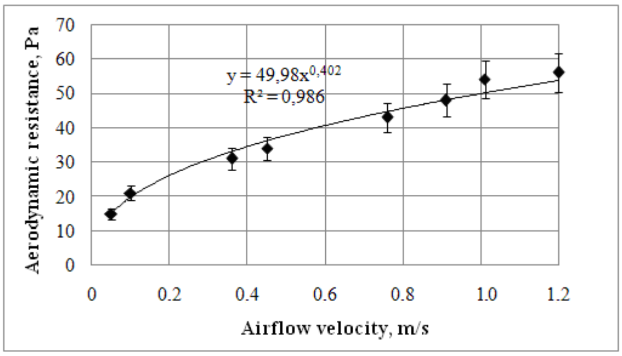

Fig 8. Biocharge's aerodynamic resistance at different velocities

With biofilter's load being increased, air resistance increases and reaches the maximum, 56 Pa, at airflow velocity in the device of 1.2 m/s (Fig. 8).

A much lower aerodynamic resistance of a charge was recorded in a plate-type biofilter than in a biofilter of a capillary structure. As investigations carried out by researchers show, the aerodynamic resistance of synthetic-origin charges depends on a charge. The resistance of a charge composed of ceramic rings used in a cassette biofilter reached 1 500 Pa (Liu *et al.* 2006). Biofilter's aerodynamic resistance of 1 700 Pa/m was achieved upon using other materials for a charge, such as a mixture of peat and bark. The lowest aerodynamic resistance, 200 Pa/m, was obtained upon using wood chips for biological treatment (Kennes and Thalasso 1998). Thus, the aerodynamic resistance of a charge in a plate-type biofilter decreases by up to 20 times. This allows a more effective use of the capacities of a biological air treatment device.

4. Conclusions

1. Biofilter's effectiveness of 90 % was recorded at extremely low loads. In order to maintain such a rate of effectiveness, the amount of air supplied to the biofilter has to be reduced by increasing the concentration of ammonia vapour in the supplied air.
2. At airflow velocity of 0.04±0.01 m/s in biocharge, biofilter's effectiveness stabilised after 35 days and ranged between 75.4 % and 78.9 %. This allows a conclusion that biocharge's bacteria have fully acclimatised to ammonia vapour.
3. The highest fall in air treatment effectiveness with regard to ammonia concentration in the supplied air was determined when air was supplied to the biofilter at the highest velocity – 0.5±0.01 m/s.
4. The aerodynamic resistance of a plate-type biofilter reaches 56 Pa. When compared to a cassette biofilter, the plate structure of a biofilter allows decreasing the aerodynamic resistance of a charge by up to 20 times.

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