ORIGINAL ARTICLES AAEM

Ann Agric Environ Med 2007, 14, 151-157

EFFICACY OF A NOVEL BIOFILTER IN HATCHERY SANITATION: II. REMOVAL OF ODOROGENOUS POLLUTANTS

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Tymczyna L, Chmielowiec-Korzeniowska A, Drabik A, Skórska Cz, Sitkowska J, Cholewa G, Dutkiewicz J: Efficacy of a novel biofilter in hatchery sanitation: II. Removal of odorogenous pollutants. *Ann Agric Environ Med* 2007, **14**, 151-157.

Abstract: The present research assessed the treatment efficiency of odorogenous pollutants in air from a hatchery hall vented on organic and organic-mineral beds of an enclosed-container biofilter. In this study, the following media were used: organic medium containing compost and peat (OM); organic-mineral medium containing bentonite, compost and peat (BM); organic-mineral medium containing halloysite, compost and peat (HM). The concentration of odorogenous gaseous pollutants (sulfur compounds and amines) in the hatching room air and in the air after biotreatment were determined by gas chromatography. In the hatchery hall among the typical odorogenous pollutants, there were determined 2 amines: 2-butanamine and 2-pentanamine, hydrogen sulfide, sulfur dioxide, carbon disulfide, sulfides and mercaptans. Ethyl mercaptan showed the highest levels as its mean concentration in the hatchery hall air exceeded 60 μg/m^3 and in single samples even 800 μg/m^3. A mean concentration of 2-butanamine and sulfur dioxide in the examined air also appeared to be relatively high – 21.405 μg/m^3 and 15.279 μg/m^3, respectively. In each filter material, the air treatment process ran in a different mode. As the comparison reveals, the mean reduction of odorogenous contaminants recorded in the hall and subjected to biotreatment was satisfying as it surpassed 60% for most established pollutants. These high removal values were confirmed statistically only for single compounds. However, a low removal level was reported for hydrogen sulfide and sulfur dioxide. No reduction was recorded in the bentonite supplemented medium (BM) for sulfur dioxide and methyl mercaptan. In the organic medium (OM) no concentration fall was noted for dipropyl sulfide either. In all the media investigated, the highest removal rate (100%), not confirmed statistically, was observed for carbon disulfide. Very good results were obtained in the medium with a bentonite additive (BM) for both identified amines, whose mean elimination rate exceeded 60% ($p \leq 0.05$). The present research proved that diethyl sulfide is most susceptible to biofiltration (over 80%) in the bed supplemented with halloysite (HM) and bentonite (BM) ($p \leq 0.05$).

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Key words: chicken hatchery, odor, air biofiltration.

INTRODUCTION

Air quality status depends mainly on the major emission from the heavy and municipal industry, yet it is seriously affected by the food industry and agriculture as well.

The industrial objects include a wide range of food industry plants that release toxic, in particular odor forming off-gases of high noxiousness, therefore it should be an issue of deep concern. At most technological processes in alcohol distilleries, breweries, wineries, dairy plants, yeasts,

Received: 26 February 2007
Accepted: 8 May 2007

spices and concentrate plants, coffee and cocoa roasters, odors are emitted as well as toxic gases, such as hydrogen sulfide, ammonia, acetone, aldehydes, methyl mercaptan [14].

In meat plants, odors are produced at each production stage, starting from slaughter, then sausage production and finally, sewage treatment and waste processing. Decomposition of raw material ingredients treated, mainly proteins, constitutes the main source of heavy toxic amines, aliphatic hydrocarbons and mecaptans. The same applies in chicken processing factories, where egg processing plants emit noxious, odor forming gases – aromatic and aliphatic hydrocarbons, aldehydes, ketones, volatile fatty acids, amines and organic and inorganic sulfur compounds [14].

The sulfurorganic compounds, in which mercaptans are formed at the anaerobic breakdown of proteins and sulfur amino acids, as well as at hydrogen sulfide oxidation, belong to the compounds widely recognized in environment where the substance matter containing sulfur rapidly decomposes [12]. These compounds were detected at animal breeding farms and incubators at chicken hatching [18, 22, 23]. Their smell is characterized as an unpleasant, irritative, nauseating, rotten egg odor (hydrogen sulfide), garlic smell (sulfides and disulfides) or sauerkraut smell (mercaptans). Besides, some of them show strong toxic properties, such as diethyl sulfide, which at high concentrations affect the respiratory and the central nervous system [19].

Regarding the noxiousness of the smell, we should strictly separate the toxic effects caused by the presence of some air ingredients from the effects contributed to the very sensory properties of a substance. However, a noxious impact of odors on the human organism may be considerable, as shown in the smell surveys run by Schiffman *et al.* [19].

In Poland, according to a Regulation of the Ministry Council of 20.12.2005 [6], every enterprise releasing harmful gases or dusts to the atmosphere is obliged to lodge pollution fees and charges. The charges scheme goes as following: a kilogram of ammonia emitted to the environment by a party - 0.34 PLN, suphur dioxide – 0.42 PLN, benzene – 6.83 PLN, carbon disulfide – 1.66 PLN and a kilogram of organic sulfur compounds – 1.00 PLN. Which is why inexpensive, simple and effective methods for the pollutants removal have been looked for.

Among the methods for odor control, the most frequent prove to be those based on adsorption processes (with use of activated carbon, zeolites), physical or chemical absorption (scrubbing), thermal, catalytic treatment, UV rays or ozone, as well as biological methods. The last decades have been marked by the development of biotechnologies. To remove the gaseous pollutants from the off-gases through biodegradation, there are applied such devices as bioscrubbers, membrane bioreactors or those discussed in the present work - biofilters. Differentiation of these installations results from the type of mobile phases, gas carriers, or the mode of active biomass location in reactors in which the direct contact with a bacteria population induces partial or complete degradation of gaseous pollutants [13].

The present research assessed the treatment efficiency of odorogenous pollutants in air from a hatchery hall vented on organic and organic-mineral beds of an enclosed-container biofilter.

MATERIALS AND METHODS

Examined facility. The investigations were carried out in the Chicken Hatchery Plant in Dębówka, 20 km of Warsaw, Poland. An annual input of the hatchery is 20-25 million broiler chickens, which constitutes ca 4% of the domestic production.

Use of a novel biofilter. In the present experiment, a biofilter was fitted to the outlet of the ventilation system of the hatchery hall with 8 Petersime hatchers (AS-4H, Petersime, Zulte, Belgium) of 115,000 eggs input each and 12 incubators (AS-4S, Petersime, Zulte, Belgium).

The biofilter of 2.0 × 1.8 × 1.8 m dimension in a stainless steel case comprised the following elements: a high pressure fan with maximum 1,500 m^3/h performance, an air humidifier and biofiltration chamber (see Figure 1 in the preceding article by A. Chmielowiec-Korzeniowska *et al.* [5]). This chamber was divided into 3 independent sections that facilitated the simultaneous evaluation of the biofiltration properties of 3 different media-beds (Fig. 1). In this study, the following media were used: • an organic medium containing 50% compost and 50% peat (OM); • an organic-mineral medium containing 20% bentonite, 40% compost and 40% peat (BM); • an organic-mineral medium containing 20% halloysite, 40% compost and 40% peat (HM).

Sampling sites. The air samples for the chemical analyses were collected at 5 measurement points (Fig. 1), 2 in the hatchery hall in front of the duct delivering contaminated air to be biotreated (points 1 and 2) and at 3 points at the air outlets from each biofiltration chamber, after biological treatment (points 3, 4, 5). At each research series, 2

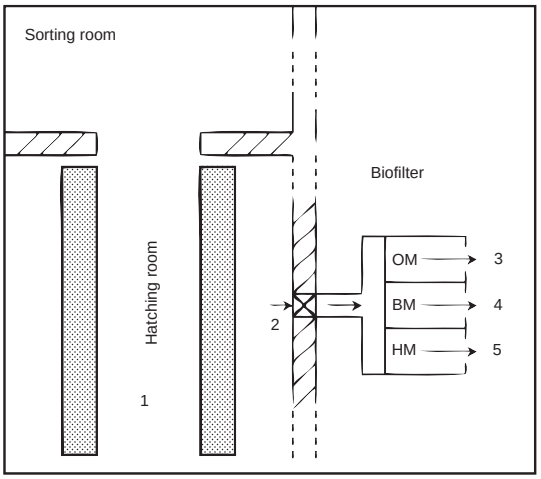

Figure 1. Site of collected air samples. 1-5 – sampling points. OM – organic medium, BM – medium with bentonite, HM – medium with halloysite.

air samples were taken from each measurement point (total 10 air samples).

Air chemical analyses were conducted together with examination of the physicochemical and microbiological properties of the filter material.

A total of 6 research series were made, i.e. in weeks 1, 10, 30, 40, 55 and 60 of the biofilter operational activity.

Determinations of air odorogenous pollutants. The odorogenous gaseous pollutants of air were determined by gas chromatography. The air samples (2-3 l) were collected with an electrical pump into Tedlar bags (Sensidyne, Inc., Clearwater, USA). The air pollutants in the samples were concentrated through adsorption, then desorbed using the kit for thermal desorption (TDV Model 890, Dynatherm, Analytical Instruments, Inc., Oxford, USA), for the chromatography system (HP 5890 series II, Hewlett Packard, Santa Clara, USA) equipped with a selective flame photometric detector (FPD) combined with S-filter of 393 nm wave length. The analysis included 2 parallel data collection paths from the chromatographic analysis: digital and analog. The gaseous solvents (chromatograms) were prepared in a permeative chamber heated to a temperature suitable for a permeative tube. On the basis of zero line analysis, the threshold values for peak detectability were established. Chromatographic analyses of the air models and samples were performed under the same operational conditions of the chromatography system.

Determination of filter material. The temperature of filter materials was measured with an electronic thermometer with sensor, a filter material reaction with pH-meter (CP-104, Elmetron, Poland), and moisture measurements were done with a gravimetric method.

The microbiological analysis of the media included determination of total count of mesophilic and psychrophilic bacteria, as well as fungi. The filter material samples for the microbiological examinations were collected to a sterile container with a disinfected soil drill. The mixed together material was sampled in the amount of 1 g specimens. Determinations were made by the plate dilution method with surface inoculation technique on adequate media. To calculate total bacteria count in the initial sample and succeeding dilutions, they were inoculated in the volume of 0.1 ml on the plates with adequate media at 2 parallel replications, and incubated at an adequate temperature for a definite time. The mesophilic and psychrophilic bacteria were inoculated on agar medium and incubated at 37ºC and 22ºC for 24 hrs and 72 hrs respectively, while fungi were inoculated on Sabouraud medium and incubated at 26ºC for 5 days. After incubation, the grown colonies were counted and the concentration of bacteria calculated in colony forming units (cfu) per gram.

Statistical analysis. The obtained results were analyzed statistically and characterized with a number of samples subjected to statistical analysis (n), arithmetic mean and standard deviation (Mean ± SD), as well as with the lowest and highest value obtained in the experiment (min. and max.). A mean level of gaseous pollutants determined in the hatchery hall air (mean from points 1 and 2) was compared using the Wilcoxon test, with the pollutants concentrations determined in the air leaving the 3 applied in parallel filter materials, i.e. at points 3, 4 and 5. On the basis of the mean levels of contaminants before and after biotreatment for each filter material used, there was computed biofiltration performance expressed as reduction per cent.

RESULTS

In the hatchery hall among the typical odorogenous pollutants, there were determined 2 amines: 2-butanamine and 2-pentanamine, hydrogen sulfide, sulfur dioxide, carbon disulfide, sulfides and mercaptans (Tab. 1). Ethyl mercaptan showed the highest levels as its mean concentration in the hatchery hall air exceeded 60 μg/m^3 and in single samples even 800 μg/m^3. A mean concentration of 2-butanamine and sulfur dioxide in the examined air also appeared to be relatively high – 21.405 μg/m^3 and 15.279 μg/m^3, respectively.

In the investigations, the odorogenous pollutants together with the vented air were pressed into the biofilter fitted at the blower outlet where, being humidified, they were washed out or broken down in the filter material through biodegradation.

In each filter material, the air treatment process ran in a different mode (Tab. 2-4). In the bentonite supplemented medium (BM) at the general decline of amine and sulfur compounds, there was noted a substantial rise of a methyl mercaptan content (Tab. 2). Its concentration in the air leaving the bed averaged 554.237 μg/m^3. Whereas, the organic-mineral material with a halloysite additive (HM) (Tab. 3) and the organic material (OM) (Tab. 4) proved quite conducive for mercaptans degradation, including methyl mercaptan. In these media, the methyl mercaptan level exceeded

Table 1. Mean concentration of sulfur compounds and amines in the hatching room air (μg/m^3); n = 22.

Compound	Mean ± SD	min.	max.
2-butanamine	21.405 ± 62.600	0.000	288.645
2-pentanamine	3.646 ± 3.156	0.000	9.445
hydrogen sulfide	8.800 ± 13.793	0.195	66.947
sulfur dioxide	15.279 ± 38.433	0.000	179.976
methyl mercaptan	3.206 ± 7.862	0.000	29.304
ethyl mercaptan	60.021± 175.373	0.000	814.438
carbon disulfide	0.769 ± 2.836	0.000	12.862
buthyl mercaptan	0.594 ± 1.683	0.000	7.891
methyl ethyl sulfide	8.386 ± 8.356	0.229	27.531
diethyl sulfide	1.522 ± 2.629	0.000	9.193
methyl propyl sulfide	2.347 ± 4.209	0.000	19.706
dipropyl sulfide	2.581 ± 3.108	0.000	12.548

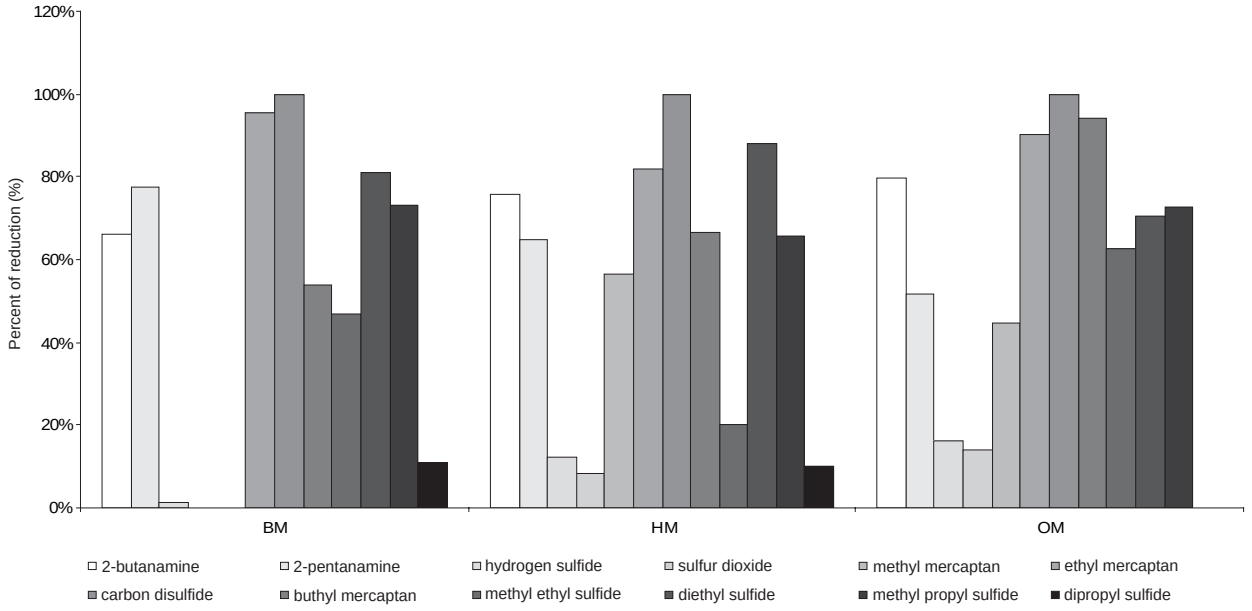

Figure 2. Efficiency values for the removal of odorogenous pollutants by the biofilter media tested throughout the experiment [%].

1 μg/m^3 only slightly. In all the filter materials used, the complete reduction of carbon disulfide was recorded. Due to great fluctuations of the determined concentrations of this compound, the difference between the levels prior to and after biofiltration was not statistically significant. With the organic medium (OM), statistical comparison revealed significant decrease of concentration only after biofiltration of methyl ethyl sulfide (Tab. 4).

On the basis of the mean concentrations of the pollutants determined prior to biofiltration – in the hall and after biotreatment, for each bed used in the investigation the mean removal efficiency was computed (Fig. 2). As the comparison reveals, the mean reduction of odorogenous contaminants recorded in the hall and subjected to biotreatment was satisfying as it surpassed 60% for most determined pollutants. These high removal values were confirmed statistically only for single compounds. However, a low removal level was reported for hydrogen sulfide and sulfur dioxide. No reduction was recorded in the bentonite supplemented medium (BM) for sulfur dioxide and methyl mercaptan. In the organic medium (OM) no concentration fall was noted for dipropyl sulfide either. In all the media investigated, the highest removal rate (100%), not confirmed statistically, was observed for carbon disulfide. Very good results were obtained in the medium with a bentonite additive (BM) for both identified amines, whose mean elimination rate exceeded 60% ($p \leq 0.05$). The present research proved that diethyl sulfide is most susceptible to biodegradation (over 80%) in the bed supplemented with halloysite (HM) and bentonite (BM) ($p \leq 0.05$).

Table 2. Mean concentration of sulfur compounds and amines in the air (μg/m^3) after biotreatment in the bentonite supplemented medium (BM).

Compound	Mean ± SD	min.	max.
2-butanamine	7.231 ± 14.381*	0.000	40.386
2-pentanamine	0.815 ± 1.140*	0.000	2.533
hydrogen sulfide	8.688 ± 11.389	0.195	42.894
sulfur dioxide	15.702 ± 30.952	0.000	105.928
methyl mercaptan	554.237 ± 1982.801	0.000	7,153.361
ethyl mercaptan	2.608 ± 4.829	0.000	14.178
carbon disulfide	0.000 ± 0.000	0.000	0.000
buthyl mercaptan	0.273 ± 0.526	0.000	1.421
methyl ethyl sulfide	4.460 ± 7.131*	0.000	22.673
diethyl sulfide	0.292 ± 0.608*	0.000	1.758
methyl propyl sulfide	0.629 ± 0.588	0.000	1.989
dipropyl sulfide	2.296 ± 2.389	0.000	6.922

*difference between the levels prior to (Table 1) and after biofiltration statistically significant for $p \leq 0.05$; n = 13.

Table 3. Mean concentration of sulfur compounds and amines in the air (μg/m^3) after biotreatment in the halloysite supplemented medium (HM).

Compound	Mean ± SD	min.	max.
2-butanamine	5.167 ± 7.037*	0.000	18.061
2-pentanamine	1.275 ± 1.729	0.000	4.17
hydrogen sulfide	7.734 ± 11.443	0.216	44.387
sulfur dioxide	13.980 ± 30.924	0.000	114.438
methyl mercaptan	1.399 ± 2.573	0.000	7.303
ethyl mercaptan	10.749 ± 23.734	0.000	82.684
carbon disulfide	0.000 ± 0.000	0.000	0.000
buthyl mercaptan	0.200 ± 0.348	0.000	1.105
methyl ethyl sulfide	6.706 ± 11.585*	0.588	33.479
diethyl sulfide	0.184 ± 0.210*	0.000	0.682
methyl propyl sulfide	0.801 ± 1.256	0.000	4.613
dipropyl sulfide	2.321 ± 2.816*	0.000	8.144

*difference between the levels prior to (Table 1) and after biofiltration statistically significant for $p \leq 0.05$; n = 13.

Table 4. Mean concentration of sulfur compounds and amines in the air (μg/m^3) after biotreatment in the organic medium (OM).

Compound	Mean ± SD	min.	max.
2-butanamine	4.350 ± 11.487	0.000	38.673
2-pentanamine	1.756 ± 2.992	0.000	9.119
hydrogen sulfide	7.369 ± 8.083	0.382	25.340
sulfur dioxide	13.151 ± 23.238	0.000	74.201
methyl mercaptan	1.779 ± 3.675	0.000	11.878
ethyl mercaptan	5.859 ± 10.183	0.000	34.949
carbon disulfide	0.000 ± 0.000	0.000	0.000
buthyl mercaptan	0.034 ± 0.117	0.000	0.407
methyl ethyl sulfide	3.136 ± 5.124*	0.000	18.747
diethyl sulfide	0.451 ± 0.298	0.000	1.016
methyl propyl sulfide	0.639 ± 0.656	0.000	1.781
dipropyl sulfide	2.618 ± 3.188	0.000	10.683

*difference between the levels prior to (Table 1) and after biofiltration statistically significant for $p \leq 0.05$; n = 12.

The determinations of the filter material, conducted in parallel with the analyses of the air chemical composition, showed that the physicochemical and microbiological characteristics of the applied media were maintained at a stable and optimal level for the biotreatment process (see Table 1 in the preceding article by A. Chmielowiec-Korzeniowska *et al.* [5]). Some minor differences were observed between the biofilter materials in the case of microbiological determinations. The organic medium (OM) appeared to be most conducive for bacteria growth, while the medium with halloysite (HM) stimulated fungus growth.

DISCUSSION

The pollutants determined in the hatchery hall air did not surpass the permissible upper limits – NDS in the working environment imposed by the Regulation of the Polish Ministry of Labour and Social Policy of 29.11.2002 [17]. Yet, it should be kept in mind that the combined occurrence of numerous pollutants may enhance their hazardous effects. The contaminants released to the air, despite their dilution, pose a serious threat for the natural environment and human health.

In Poland, the obligatory threshold limit values for the atmospheric air pollutants also include the compounds determined in the hall air, including heavily odorogenous mercaptans, carbon disulfide, hydrogen sulfide, and sulfur dioxide [15]. Theoretically, these values may be exceeded if the pollutants concentration levels are regularly determined and the ventilation system efficiently carries them outdoors. Therefore, it is quite justifiable that biofilters are fitted at the ventilation system outlet and vented air treated before it reaches the environment.

In the biofiltration process different filter materials can be used. Efficient running of the natural biodegradation processes of the toxic and odorogenous gaseous substances requires optimal environmental conditions where the biofiltration proceeds as well as application of a suitable material in order to make full use of its biological potential. Due to the fact that adsorption is a crucial and primary process of pollutants reduction, the materials of large surface area are used [2, 10].

Clark and Wronowski [6] report that nearly all organic materials are recommended for biofilter filling as they show the proper composition and adequate structure. Bohn [3] mentioned 13 major physical, chemical and biological properties of proper filling. Among the most vital physical properties are: extensive surface area providing optimal conditions for microbial development, as well as high porosity to prevent a fall in pressure or clogging problems, and finally, proper oxygenation in the biofilter. These properties characterize the filter materials used in the present investigation, i.e. peat, compost and the mineral supplements: bentonite and halloysite.

Bentonites are the materials of wide application, and due to their sorptive properties are frequently used as a decolourant and sorptive agent in the chemical industry, food industry and agriculture. Halloysites are also employed due to their absorption power, yet contrary to bentonites, are less frequently used for environment protection [11]. The high porosity of these materials mixed with the organic material improved the medium structure, and provided uniform oxygen distribution in a profile which constitutes a very important factor in the pollutant biodegradation, vital for the development of aerobic heterotrophic bacteria. Among the 3 tested filter materials, a mixture of compost and halloysite (HM) exhibited the best properties treating the air from the odorogenous pollutant groups, in which the presence of sulfurorganic and amines in the agricultural-industry is inevitable. In this medium, the removal rate reached a level above the mean values, and showed the slightest fluctuations noted for the results obtained for the other 2 beds. The results given by Sheridan *et al.* [20] were also characterized with very great fluctuations. The authors treated the air from a pig house where its composition was similar to that from the hatchery hall air; wood shavings were used as the biofilter medium. Throughout 63 days of the biofilter operational activity, sulfur compounds elimination reached only 9%, ranging from minus 147%-51%.

The filter material enrichment with bacterial flora, introduced with compost from the treated sewage and horse manure, provided very favourable conditions for gaseous pollutants removal [21]. Average performance of air treatment from the organic contaminants at the application of a mixture of peat, compost from sewage treatment plant, fermented horse manure and wheat straw was 66%, while for the organic sulfur compounds – 51% [4, 21].

Biofiltration efficiency, in which activity of bacteria is dependent not only on quality and quantity of a microbial population developing in the medium, but also on the physicochemical properties of the filter material: moisture, temperature, pH and the chemical composition, mainly a

carbon, nitrogen and phosphorus ratio. The biofilter material should not contain toxic compounds, because heavy metals may decrease the degradation rate. The optimal temperature of the process varies from 20-40ºC, pH value within the neutral range, with an optimal air moisture above 90%. A major problem is maintaining a proper (40-60%) moisture level in the filter solid layer responsible for the metabolic activity of microorganisms. Auria *et al.* [1] report that even a temporary moisture decline may induce irreversible results in the microbial population growth. Besides, a fall in moisture content is likely to lower pollutants elimination performance. On the other hand, a too high moisture content contributes to anaerobic conditions development and increased pressure. In practice, it is advisable to avoid in the biofilter anaerobic conditions that are conducive to the odorogenous compounds production and, in turn, lessen the pollutants removal efficiency [8].

At the biofilter start-up and medium operation, the continuous monitoring of these parameters should be performed and during the experimental period the filtration process thoroughly observed to provide the most suitable material ensuring permanent high efficiency of air control throughout the exploitation time. The determinations of the filter material carried out along with the chemical composition analyses proved that the physicochemical and microbiological properties of the media remained at a stable level optimal for the treatment process.

The available Polish and foreign literature most often presents simulation investigations of single compound degradation in laboratory-scale tests [7]. However, quite rare are studies undertaken in production conditions where the released gaseous contaminants are not homogenous but constitute a mixture of different chemical substances. The present work is one of the few attempts to tackle this problem under real conditions. The research carried out showed a relatively high differentiation of bioreduction and even if not all the compounds were removed, a smell noxiousness level was noticeably lower in the plant.

Currently, the implementation of biofilters and some other biotechnological solutions into the agricultural practices may be an ecologic necessity, drawing the increasing concern of society as well as the legislative bodies oriented towards higher standards of environment protection, and the real economic effects for the breeders. Another aspect of the undertaken investigations is considering the possibilities of biofilters installation at the actual source of pollutants production, which is the hatchery hall. Hazard prevention and air control in the working environment lower workers exposure to some harmful agents, such as malodors, including sulfides and mercaptans.

CONCLUSION

In the research performed, the most efficient air treatment from the odorogenous contaminants was found for biofilter chambers with organic-mineral fillings. Compost and peat supplemented by 20% halloysite or bentonite significantly improved the level of gaseous odorogenous pollutants removal, especially of amines and sulfides.

REFERENCES

1. Auria R, Aycaguer AC, Devinng JS: Influence of water content on degradation rates for ethanol in biofiltration. *J Air Waste Manage Assoc* 1998, **48**, 65-70.

2. Bohn HL: Odor removal by biofiltration. **In:** Gnyp DR, Gnyp A (Eds): *Recent Developments and Current Practices in Odor Regulations, Control and Technology. Trans Air Waste Mgmt Assn*, 135-147, Derezno 1991.

3. Bohn HL: Biofilter media. **In:** *89th Annual Meeting & Exhibition Air & Waste Management Assoc* 96-WP87A.01, Nashville, Tennessee 1996.

4. Chmielowiec-Korzeniowska A, Tymczyna L, Drabik A, Malec H: Biofiltration of volatile organic compounds in the hatchery. *Ann Anim Sci* 2005, **5(2)**, 371-378.

5. Chmielowiec-Korzeniowska A, Tymczyna L, Skórska Cz, Sitkowska J, Cholewa G, Dutkiewicz J: Efficacy of a novel biofilter in hatchery sanitation: I. Removal of airborne bacteria, dust and endotoxin. *Ann Agric Environ Med* 2006, **14**, 141-150.

6. Clark RC, Wronowski A: Biofilters for sewer pump stationvents: influence of matix formulations on the capacity and efficiency of odorant removal by an experimental biofilter. **In:** Dragt V, van Ham J (Eds): *Biotechniques for Air Pollution Abatement and Odour Control Policies*, 183-186. Amsterdam, The Netherlands 1992.

7. Classen JJ, Young JS, Bottcher RW, Westerman PW: Design and analysis of a pilot scale biofiltration system for odorous air. *Am Soc Agr Eng* 2000, **43(1)**, 111-118.

8. Deshusses MA: Biological waste air treatment in biofilters. *Environ Biotech* 1997, **8**, 335-339.

9. Edwards FG, Nirmalakhandan N: Biological treatment of airstreams contaminated with VOCs: An overview. *Wat Sci Tech* 1996, **34**, 565-571.

10. Kennes Ch, Thalasso F: Waste gas biotreatment technology. *J Chem Technol Biotechnol* 1998, **72**, 303-319.

11. Kołacz R, Dobrzański Z, Kulok M, Korniewicz D, Pogoda-Sewerniak K: Wpływ dodatku haloizytu do paszy na poziom wybranych parametrów hematologicznych i biochemicznych krwi tuczników. *Zesz Nauk AR Wrocław* 2004, **350**, 102-119.

12. Pearson CD: The determination of the trace mercaptans and sulfides in natural gas chromatography – Flame photometric detector technique. *J Chrom Sci* 1976, **14**, 154-158.

13. Ramírez-López E, Corona-Hernández J, Dendooven L, Rangel P, Thalasso F: Characterization of five agricultural by products as potential biofilter carriers. *Bioresource Technol* 2003, **88**, 259-263.

14. Rappert S, Müller R: Odor compounds in waste gas emissions from agricultural operations and food industries. *Waste Manage* 2005, **25**, 887-907.

15. Rozporządzenie Ministra Środowiska z dnia 5 grudnia 2002 roku w sprawie wartości odniesienia dla niektórych substancji w powietrzu. Dz.U. z dnia 8 stycznia 2003 r., Warszawa 2003.

16. Rozporządzenie Rady Ministrów z dnia 20 grudnia 2005 roku w sprawie opłat za korzystanie ze środowiska. Dz.U. z dnia 29 grudnia 2005 r., Warszawa 2005.

17. Rozporządzenie Ministra Pracy i Polityki Społecznej z dnia 29 listopada 2002 roku w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy. Warszawa 2002.

18. Saba L, Sławoń J, Tymczyna L, Bis-Wencel A: Emisja odorów siarkoorganicznych z ferm zwierząt futerkowych. *Ann UMCS sec. EE* 1996, **30**, 183-187.

19. Schiffman SS, Sattely Miller A, Suggs MS, Graham BG: The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. *Brain Res Bull* 1995, **37**, 369-375.

20. Sheridan BA, Curran TP, Dodd VA: Assessment of the influence of media particle size on the biofiltration of odorous exhaust ventilation air from a piggery facility. *Bioresource Technol* 2002, **84**, 129-143.

21. Tymczyna L, Chmielowiec-Korzeniowska A: Reduction of odorous gas compound in biological treatment of ventilation air from layer house. *Ann Anim Sci* 2003, **3(2)**, 389-397.

22. Tymczyna L, Maińska A, Malec H, Saba L: Ocena emisji merkaptanów w procesie inkubacji jaj. *Ann UMCS sec. EE* 2000, **29**, 223-229.

23. Tymczyna L, Saba L, Malec H, Maińska A: Ocena stężenia odorów w procesie inkubacji jaj kurzych. *Rocz Nauk Zoot* 2000, **27(3)**, 229-237.