Biological Treatment of Laying House Air with Open Biofilter Use

L. Tymczyna*, A. Chmielowiec-Korzeniowska, L. Saba

Department of Animal and Environmental Hygiene, University of Agriculture in Lublin,
ul. Akademicka 13, 20-950 Lublin, Poland

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Abstract

This experiment examined the efficiency of biological removal of air contaminants performed with a prototype "open" biofilter. The biofilter bed composed the following components by weight: 35% fibrous peat, 35% sallow peat, 10% barley straw, composts from sewage plant and horse manure -10% each. With Waters` liquid chromatograph use there was determined a content of ammonia, nitrates, nitrites, sulphates, chloride phosphates, iodides, bromides and fluorides in the air. The examinations on the physico-chemical properties of medium and air pollution were run over 180 days, collecting the samples on the 5th, 35th, 65th, 95th and 180th biofiltration days.

After 35 days there was recorded stabilization of temperature, moisture, reaction, dynamic growth of total bacteria count and coli titre in the medium. Ammonia biofiltration efficiency ranged from 36 to 89%, while for nitrates, nitrites and phosphates it was even higher than 66-100%.

Keywords: air biofiltration, bed properties, microflora, pollutants, laying house

Introduction

Biofiltration is a relatively new technology for air pollution control (APC) where toxic and odorous off-gases are subjected to biodegradation on specific beds. The biofiltration can be successfully applied wherever pollutant concentrations are low, yet they appear in a wide range in high volume of air. The techniques for biological air treatment have been well established in numerous countries to treat specific types of emission sources - sewage treatment plants, incinerating plants, chemical and petrochemical industry, food-agricultural processing factories as well as the animal breeding sector [1, 4, 6, 12, 14]. All these sources generally emit large amounts of toxic and odorous waste gases.

In some European countries, like Germany or The Netherlands, as early as in the 1980s stringent regulatory requirements were introduced to control air toxics. This fact promoted the development of further studies in this field. The data from the European Union Commission showed that investment outlay for air biological protection in Germany was to surpass 11 billion DM. According to the German Environmental Protection Office over 100 biofilters and 200 bioscrubbers are active [4].

The methods for air pollution control are predominantly based on two processes: the adsorption of air contaminants and their biodegradation due to the activity of some specific microorganisms that are deliberately introduced onto the filter material. End products from the biological decomposition are CO_2 and H_2O as well as microbial biomass containing many groups of microorganisms [3, 11, 18].

Together with gaseous pollutants some others, including biological ones, get to the biofilter. A bacterial-dust aerosol introduced upon start-up undergoes absorption on the biofilter bed and perishes competing with the resident microbial population or finds good conditions for development, gets over the acclimation period and metabolizes the target pollutants [9]. The studies on air toxics vented

*Corresponding author; e-mail: tymczyna@ursus.ar.lublin.pl

from the poultry house showed it is usually polluted with numerous kinds of microorganisms, both saprophytes and pathogenes. Among them, *Escherichia coli* was the most detected most often being excreted with animals` faeces. Enteropathogenic strains of *E.coli* make a secondary source of infection at animal farms [13, 16].

Faeces are also inhabited by the other bacteria responsible for emission of odorous off-gases from faeces, these are volatile fatty acids, amines, ammonia, indole and phenol as well as the compounds containing sulphur (mercaptans). Here belong bacteria of *Streptococcus*, *Peptostreptococcus*, *Eurobacterium*, *Lactobacilli*, *Escherichia*, *Clostridium*, *Propionibacterium*, *Bacteroides* and *Megasphara* [2, 5, 15]. When dung is drying up the microorganisms are taken out together with vented air.

The major objective of the present study was to determine the biofiltration removal efficiency of chemical and biological air contaminants from off-gas stream vented from a laying house with a prototype "open" biofilter.

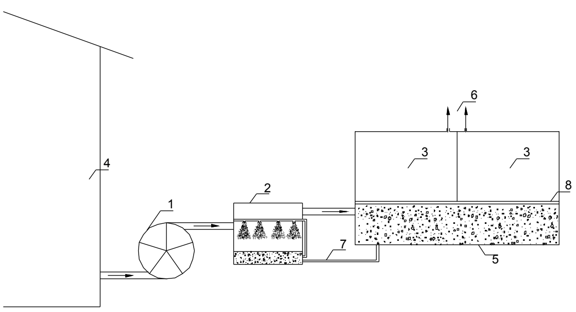
Materials and Methods

A scheme of an open prototype biofilter system is presented in Fig.1. Biofilter construction comprises the following elements: a high pressure blower of 3500 m^3/h performance, air humidification chamber and specific biofilter bed. The humidifier was connected with a spray nozzle compressor.

The filter material consisted of: fibrous peat (35% gravimetric composition), coarse-grained peat (35%), wheat straw (10%), compost from sewage treatment plant (10%) and from horse manure (10%). The biofiltration chamber had 10 m^2 area and the bed was 1.2 m in height. Off-gas stream from a poultry house was pressed into the humidifier where waste gas reached moisture 95% and was vented to the biofilter bed.

The experiment was run at the reproductive hen farm in "D" near Góra Kalwaria for 180 days. The analyses were made on the 5^{th}, 35^{th}, 65^{th}, 95^{th} and 180^{th} days following filling the chamber with the medium.

Content of ammonia, nitrates, nitrites, phosphates, chlorides, sulphates, iodides, bromides and fluorides was determined with ion chromatography technique. Air pollutant composition was examined in the laying house and biofilter. In each series of examinations air was sucked into bubblers at five sites of the poultry house and the biofilter chamber. Inorganic compounds content in the air was determined at Waters` liquid chromatograph connected with the analytical column filled with anion solvent and collaborating with conductometric detector and UV.



1 - blower, 2 - humidifier, 3 - biofilter bed, 4 - laying house, 5 - air distribution, 6 - clean gas, 7 - drainage, 8 - metal grate

Fig. 1. A scheme of a prototype biofilter.

There were also made the physicochemical and microbiological examinations of the biofilter medium determining its pH, temperature, moisture, total content of microorganisms and coli titre.

Total number of microbes was fixed with submerged inoculation on agar according to PS – ISO 6222. Coli titre was examined by a fermentation method on brilliant green agar after the Polish Standard PS 77/A – 86031. The medium reaction was determined by pH-meter. Moisture evaluation was performed by a gravimetric method by drying a weighed portion up to obtain dry mass. A temperature in the media was fixed with the sensors connected with a conductometer.

The results were subjected to statistical analysis. Mean titres of coli and total count of bacteria in each period as well as the levels of inorganic air pollutants compounds in laying house and behind the biofilter were compared with T-Student's test. Air biofiltration performance was expressed by % reduction of gaseous pollutants.

Results and Discussion

Many macro- and microkinetic processes are involved in the operation of the biofilter medium. Macrokintetic basis is the transport of substrate molecules followed by biodegradation due to microorganisms resident in the "biofilm" layer. Air-cleaning process performance is a result of oxygen and other gases introduced [4].

Biofiltration depends highly on the activity of meso- and thermophylic microorganisms. Filter removal efficiency is also conditioned by its physicochemical properties. Reaction, moisture and temperature are vital in this respect. Degradation rates increase with temperature. Medium high temperature can reduce the number of pathogenes introduced together with off-gas stream. The optimum biofiltration temperature ranges between 20 and 40°C. The other factor deciding its efficiency is the optimum air moisture maintenance (90-99%) and that of moisture (40-60%) [1, 4].

The experiment was conducted from early spring to autumn 2001. The atmospheric air temperature oscillated from –2.6°C to +29.1°C. The physico-chemical properties of the biofilter bed changed slightly over the time of biofilter operation (Tab.1). At start-up the biomass temperature was fairly low and did not exceed 15°C. That may indicate not intensive activity of mesophylls. During summer the temperature increased by 10°C. Biomass moisture ranged from 64-71%, just like the medium reaction. At the beginning, owing to high share of peat, the pH proved to be a little acidic, yet it got stabilized at a slightly alkaline level after 35 days of biofilter operation. The conditions in the medium

Table.1.Physico-chemical and microbiological properties of biofiltering material.

Time of biofilter work (day number)	Coli titre[1]	Total number of bacteria[2]	Temperature [^{0}C]		Moisture [%]		pH	
			M	SD	M	SD	M	SD
5	10^{-4}	2.8×10^8	14.1	0.4	71.6	5.1	6.6	0.3
35	10^{-3}	4.7×10^{10} a	14.9	0.4	71.7	2.1	7.5	0.4
65	10^{-3} a	8.1×10^{10} ab	18.5	1.5	64.2	6.4	7.6	0.3
95	10^{-3}	1.1×10^{11} bc	15.9	0.9	70.0	3.1	7.5	0.3
180	10^{-4} a	1.9×10^{11} c	24.5	0.5	64.4	3.1	7.6	0.2

[1] statistical significance for mean difference denoted with the same letters
[2] statistical significance for mean difference denoted with different letters

Table 2. Inorganic compounds level in air ventilated from poultry house and biofilter (mg/m^3).

Time of biofilter work (day number)	Sampling site	Compound type					
		Ammonia	Nitrates	Nitrites	Phoshates	Chlorides	Sulphates
5	laying house	23.87	0.10 b	0.62 c	0.03 d	0.33 e	0.82 f
	biofilter	15.33	0 b	0 c	0 d	0.04 e	0.24 f
	% of reduction	36	100	100	100	88	71
35	laying house	24.53	1.11	0.65 c	0.87 d	0.45 e	0.77 f
	biofilter	7.83	0.38	0.03 c	0.02 d	0.01 e	0.09 f
	% of reduction	68	66	96	97	98	89
65	laying house	28.93 a	0.97 b	0.56 c	0.66 d	0.47 e	0.60
	biofilter	7.9 a	0.21 b	0.09 c	0.03 d	0.01 e	0.11
	% of reduction	73	78	84	95	98	82
95	laying house	34.70 a	0.65 b	0.02	0.32 d	0.80 e	0.37
	biofilter	3.77 a	0 b	0	0.03 d	0.12 e	0.31
	% of reduction	89	100	100	91	85	17
180	laying house	19.90 a	0.05	0.03	0.07 d	0.07	0.50 f
	biofilter	6.55 a	0.05	0.01	0.02 d	0.04	0.21 f
	% of reduction	67	0	70	73	40	58

statistical significance for differences (at $p < 0.06$)denoted with the same letters

were similar to those optimum for biofilm microflora development.

In the biofilter bed investigated there was observed a rapid growth of total count of bacteria and coli titre. The statistically significant differences were determined in the successive series of analyses (Tab.1). This increasing number of bacteria testifies to a violent development of the biofilm layer in molecules. Their proliferacy is a result of the favourable physico-chemical conditions and sufficient quantity of nutrients and oxygen.

In the poultry house air toxic ammonia concentrations exceeded the zoohygiene standards for poultry. Its values for the young poultry should not surpass 10 mg/m^3, while for adults 20 mg/m^3. The maximum admissible concentration of chlorides is 0.1 mg/m^3, for sulphates – 0.5 mg/m^3. The chloride concentrations in laying house air exceeded the values many times. The sulphates in air are readily absorbed onto fine particles of dust. Being inhaled by the animals they penetrate into follicular space of lungs and a tracheo-bronchial segment and damage the ciliated epithelium. They cumulate in the trachea walls, bronchi, liver, brain and lymph nodes [15]. The chlorine compounds of increased concentrations are also absorbed into the organism by the respiratory tract, here the fastest, alimentary tract or the skin. Mechanism of chlorine compounds intoxication consists in the damage of the central system of respiration, haematopoetic and parenchymatous organs.

According to the authors of other studies, biofilter efficiency removal may range between 70 and 99% and depends on the input type [1, 3, 7].

The present authors` results demonstrate high performance and effectiveness of the biofilter. In the laying house waste gas the following inorganic compounds were fixed: ammonia, nitrates, nitrites, phosphates, chlorides and sulphates. Their concentrations surpassed the zoohygiene standards for poultry or maximum admissible concentrations for atmospheric air in many samples (Tab.2). Ammonia reduction degree was rather low –36% in the initial phase of the experiment (after 5 days) and then it increased to reach 89% after 3 months of biofiltration. Even more favourable results in gaseous pollutant reduction were obtained for nitrates, nitrites, phosphates and chlorides. Quite considerable range of reduction degree was recorded for sulphides, from 17% to 89%.

The long-term process (3-5 years) of the organic matter mineralization in biofilter leads to the changes in its structure, mainly the medium porosity and its removal efficiency reduction. That may also happen at temporary shut-down of a biofilter being conducive to anaerobic conditions development. The results obtained in the last series of measures confirm this statement. In this period due to blower breakdown the sufficient nutrients were not provided by the filter material; therefore, a drop of biofilter removal efficiency as well as a decrease of pollutant reduction degree was reported (Tab.2).

Air protection made the main subject matter of the Climatic Convention from Kyoto and Berlin, which was ratified by Poland in 1995. One of its dominant assumptions was the reduction of hothouse gase emissions and acid rain. The basic components of acid rain are compounds of sulphur and nitrogen. They include acidforming gases SO_2, H_2S, NO_x as well as ammonia, forming ammonium salt aerosols that, due to ion NH_4 nitrification, make a source of hydrogen ions (10). Recently, sulphur oxide emissions in Europe have decreased, while ammonia has been kept at a similar level; agriculture is its main source.

An air-cleaning process that is successfully performed by various "open" or "enclosed" biofilter constructions may soon become technology for air treatment. It relies on highly competitive biofilters and relatively low operating cost as compared to other air-pollution control methods. Throughout the working period the total operation and maintenance cost is to cover only the blower operation and water supply to keep the required bed`s moisture content.

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