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COMPARING THE EFFICIENCY OF REDUCING GAS EMISSIONS FROM PIGGERY USING AIR BIOFILTER AND WATER CURTAIN*

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Celem przeprowadzonych badań było określenie możliwości redukcji emisji domieszek gazowych poprzez filtrację powietrza wentylowanego z chowu alkierzowego trzody chlewnej. Podczas badań oznaczono grupy związków gazowych w powietrzu filtrowanym i bez filtracji (grupa kontrolna) z utrzymania trzody chlewnej oraz porównano efektywność zastosowania biofiltra powietrza z różnymi mieszankami stanowiącymi jego złożę oraz biofiltra powietrza ze wspomnianymi wyżej mieszankami wyposażonego w kurtynę wodną. Największą 85% redukcję emisji uzyskano dla amoniaku. Różnica ta była wysoko istotna statystycznie dla wszystkich rodzajów mieszanek. Większą skutecznością redukcji emisji NO, NO_2, NO_x i CO_2 odznaczył się biofiltr z kurtyną wodną. Najlepszymi właściwościami filtracyjnymi w biofiltrze z kurtyną wodną cechowała się mieszanka zawierająca w swoim złożu zwiększoną ilość słomy, a w biofiltrze bez kurtyny wodnej mieszanka ze zwiększoną ilością trocin.

Słowa kluczowe: emisja GHG, biofiltr powietrza, złoża biofiltracyjne, kurtyna wodna, utrzymanie świń

The problem of emissions of gases responsible for environmental pollution is analyzed by many scientific institutions, as well as national and international organizations. These institutions have developed assumptions and programs aimed at determining the volume of emissions of gas admixtures, monitoring of these compounds and the results of their interactions. An integral part of these activities includes scientific researches of the possibility to reduce the amount of gaseous compounds released from animal production into the atmosphere. Having considered the foregoing, it is necessary to conduct studies in our country on a number of livestock species in order to determine the possibility of reducing the emission of harmful gas admixtures. Taking into account the current state of the problem, it is suggested to conduct studies to determine the possibilities of reducing emissions of gases produced from pig production through the biofiltration of used air. Negative environmental effects of pig production includes four categories. The first is excessive deposition in the soil and aquatic environment of biogenic elements, leading to excessive fertilization, eutrophication, and subsequent contamination of these habitats. The main factor is the so-called by-products, in the form of manure and slurry. The next three

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categories are associated with the emission of compounds, known in zootechnics as harmful gaseous admixtures. These include ammonia, carbon dioxide, hydrogen sulphide, nitrogen oxides, methane, ozone, and even water vapor (Demmers et al., 1999). These gases, emitted into the troposphere together with ventilated air, interact resulting in amplification of the greenhouse effect and the formation of acid rains (Van der Peet Schwering et al., 1999). The last category includes stratospheric reactions leading to the disappearance of the ozone layer which protects living organisms from ultraviolet radiation and high-energy cosmic radiation. Before studies confirmed the harmful effects of these gases on the natural environment, their negative impact on pigs has long been known (Atkinson & Watson, 1996; Chapin et al., 1998). Prolonged persistence in concentration of these admixtures which exceeds the standards results in a number of behavioral, histological, physiological, biochemical, immunological, and even pathogenic or pathological consequences (Jeppsson, 1998; Burton et al., 1998).

The aim of the study was to determine the possibility of reducing the emission of gaseous mixtures produced in pig production through the use of an air biofilter without a curtain, as well as with a water curtain in indoor breeding of fattening pigs maintained on litter in groups. The studies assumed that e.g. the sorption-filtering properties of the bed mixtures, as well as the solubility of gaseous admixtures and their binding by water may reduce their emission accompanying the maintenance of pigs.

Materials and methods

The experimental material consisted of a mixture of 3 biofiltration beds on the basis of peat (1), straw (2) and sawdust (3), and air pumped into these deposits from climatic chambers, passing through the water curtain. Climatic chambers were used to keep 120 fattening pigs of hybrid breeds (Polish Landrace × Polish Large White) × Duroc. The animals were fed in accordance with the Polish standards for pig feeding (2014) from feeding machines, with constant access to water and were kept in groups of 10 animals in each chamber, in successive repetitions. The fattening period was 110 days.

For the biofiltration of exhaust gases, while taking into account the limited properties of sorption-filtering of natural organic materials, and at the same time bearing in mind that this is not the only feature to be taken into account when selecting the bed, a mixture of: peat (high absorption), chopped straw (relatively high absorption) and pine sawdust (large porosity of the material) was used:

– the first mixture (1) was composed with the following proportions: 50% peat; 25% chopped straw and 25% sawdust;

– the second mixture (2) contained: 50% chopped straw, 25% peat and 25% sawdust;

– third biofilter mixture (3) comprised: 50% sawdust, 25% peat and 25% chopped straw.

In order to determine the effectiveness of gas emission reduction, the experiment used a metal rectangular-shaped biofilter, enclosed with sheet metal. A metal basket filled with a suitable filter bed was placed in the middle of the body at 1/3 of the height. The used air from the building was fed to the biofilter mechanically, by a pressure fan, and then sucked through the bed by an extractor fan, and discharged outside. Compared to other structures, a water curtain was used in one of the biofilters.

Water from the curtain's circulation flowed through the beds of mixtures containing organic material, thus eliminating molecules of dissolved chemical compounds. The 0.9 m × 0.9 m × 0.9 m bed itself, with a composition determined in tests was experimentally conditioned and stabilized in terms of microflora before its use in the biofilter. Gas admixtures contained in the air ventilated from the building were dissolved and bound by water and filter material. The embedded compounds were then used in metabolic processes of the microflora. The bed insert, which was replaced on a weekly basis, was used as a natural fertilizer. There are ongoing researches including the replication of the microflora in the deposit, and its saturation, the results of which will be published in a separate study.

The experiment was carried out at Experimental Station of National Research Institute of Animal Production Rudawa Ltd., and used a litter breeding systems, where each fattening pig group had a separate climatic chamber with optimal microclimate, standardized according to zootechnical standards. The studies were conducted in three repetitions: from May to August, from September to December, and from January to April.

Experiment System

Task	Repetition	No biofilter	Air biofilter/Air biofilter with water curtain		
			(1) biofiltration substrate mix	(2) biofiltration substrate mix	(3) biofiltration substrate mix
Pig housing	1.	10	10	10	10
	2.	10	10	10	10
	3.	10	10	10	10

In each repetition, differences in the composition and concentration of gaseous admixtures emitted in the air from the tested species, and the effects of various types of biological materials on the composition, concentration and reduction of gases were determined.

Type of data and collection method

During each repetition the following measurement data were collected:

– air temperature in climatic chambers – continuously;

– air temperature in supply air ducts – simultaneously with gas measurement;

– air temperature in exhaust ducts – simultaneously with gas measurement;
– relative humidity in the supply duct – simultaneously with gas measurement;
– relative humidity in the exhaust duct – simultaneously with gas measurement;
– relative humidity in climatic chambers – continuously;
– speed of air movement in the climatic chamber – simultaneously with gas measurement;
– speed of air movement in the exhaust duct – simultaneously with gas measurement;

Microclimatic measurements were carried out using an electronic monitoring system from Jotafan in a continuous manner with digital recording;

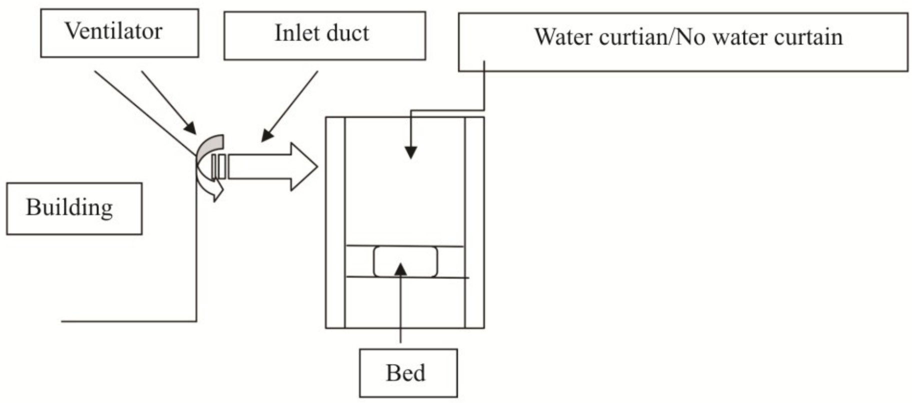
– concentrations of VOC, ammonia, nitrogen oxides, methane and carbon dioxide in the air of climatic chambers, where fattening pigs were kept and at the biofilter outlet;

– concentrations were measured daily between 8.00 a.m., 1.00 p.m. and 7.00 p.m. The measurement individual gas admixture concentrations was carried out with a Voyager gas chromatograph from Photovac;

– the emission of individual gas admixtures per unit of time, calculated per unit, was calculated from the volume of air flow and the gas concentration in it, divided by the number of animals and presented in kg/unit/year. The foregoing emission unit was used when referring to the tests of gas emissions from animal production, confirmed in the literature;

– determination of the composition of biofiltration deposits.

Biofilter scheme[1]



All research tasks were carried out in climatic chambers based on experiments from the so-called "Climatic-respiration chamber". Their

[1] Authors do not describe and do not ilustrate detailed operation and construction of biofilter, beacuse it is a subject of patent design.

construction and execution allowed to achieve complete tightness of the rooms. The inflow and removal of air occured therethrough a computer-controlled, negative-positive pressure ventilation system. A predetermined volume of air, forced mechanically through the ventilation inlet, was passed through the chamber and, it was also mechanically removed by the exhaust air duct. Both the composition of the inlet and outlet air was subjected to the monitoring. The flow was controlled by an electronic controller. The volume of the flowing air was calculated from the measured velocity of the movement, its duration and the known cross-section of the measurement channel (exhaust) using an equation applied in physics, describing the so-called "right of flow". All climatic chambers are located in one building. Each chamber was supplied with a separate ventilation duct, the inlet of which is located outside the building, outside the waste air discharge zone.

Results

The room microclimate

Considering the average values of temperature, humidity and speed of air movement in air ducts and chambers, collected during subsequent repetitions in Tables 1 and 2, it should be stated that differences in their mean values between individual groups of biofilters are not significant. This is the result of the methodical assumptions and technical capabilities of the chambe equipment. The ventilation system has the ability to regulate both the air flow and its temperature in accordance with the pre-set values. Standardization of chamber parameters allowed to compare the filtration capacity of biofilters depending on the filter cartridge being used.

Table 1. Mean values of microclimate parameters in the supply ducts of climatic chambers for pigs

Parameter	Control group – without filtration	Group/Biofilter type					
		biofilter without curtain			biofilter with curtain		
		(1) biofilter bed mix	(2) biofilter bed mix	(3) biofilter bed mix	(1) biofilter bed mix	(2) biofilter bed mix	(3) biofilter bed mix
Temperature (^{o}C)	11.7	12.1	12.5	11.9	12.3	12.4	11.8
Relative humidity (%)	61.9	61.9	62.4	61.1	60.8	61.4	61.2
Rate of air movement m/s)	0.42	0.41	0.45	0.39	0.43	0.43	0.45

Table 2. Mean values of microclimate parameters in the climatic chambers for pigs

Parameter	Control group – without filtration	Group/Biofilter type					
		biofilter without curtain			biofilter with curtain		
		(1) biofilter bed mix	(2) biofilter bed mix	(3) biofilter bed mix	(1) biofilter bed mix	(2) biofilter bed mix	(3) biofilter bed mix
Temperature (°C)	17,30	17,70	16,92	17,50	17,10	17,30	16,90
Relative humidity (%)	72.50	72.60	74.00	70.80	68.70	72.00	69.20
Rate of air movement (m/s)	0.30	0.23	0.30	0.21	0.32	0.28	0.29

Table 3 Emission rates of chemical compound groups from the piggery at the exit of the biofilter with and without water curtain (kg/animal/year)

Group of compounds	Control group – without filtration	Group/Biofilter type					
		Biofilter without curtain			Biofilter with curtain		
		(1) biofilter bed mix	(2) biofilter bed mix	(3) biofilter bed mix	(1) biofilter bed mix	(2) biofilter bed mix	(3) biofilter bed mix
VOC	0,024a	0,022a	0,030a	0,028a	0,024a	0,022a	0,024a
NH_3	0,33A	0,05B	0,09B	0,04B	0,05B	0,06B	0,07B
NO	0,014a	0,027b	0,021b	0,023b	0,012a	0,005c	0,002c
NO_2	0,095A	0,084A	0,084A	0,019C	0,052B	0,047B	0,061B
NO_x	0,109A	0,111A	0,105A	0,42B	0,064B	0,052B	0,063B
CH_4	0,51a	0,49a	0,48a	0,50a	0,49a	0,48a	0,48a
CO_2	160a	144b	151a	145b	128c	140b	133c

a, b – significant differences at P≤0.05; A, B – significant differences at P≤0.01.

Measurement of gas emissions from biofilters

When comparing the effectiveness of using biofilter bed mixtures with the water curtain and without it in fattening pig housing (Tab. 3), the reduction in VOC was not confirmed by statistical significance of the differences. The reduction level for both biofilters was low in both mixtures 1 and 2. In case of mixtures 2 and 3 for the biofilter without a curtain, the VOC emission value was slightly higher compared to the control group. The largest emission reductions were achieved in case of ammonia. This difference was statistically significant in relation to the control group for all types of blends in two types of biofilter. The mixture 3 containing 50% sawdust and 25% peat and straw applied in biofilter without water curtain demonstrated the highest efficiency in ammonia reduction, yet mixture 1 composed of 50% peat was just a little less effective, reducing the emission of this gas in biofilter with and without the air curtain to the same extent. The reduction of this gas emission in two biofilter types compared to the control group results in 85% reduction. The usefulness of biofiltration mixture 3 was also statistically confirmed with about 85% reduction of NO in biofilter with water curtain, and mixture 2 containing 50% straw was just slightly less effective. Reduction of nitric monoxide was statistically significant in case of a biofilter with a water curtain, whereas higher emissions of this gas were recorded in the biofilter without a curtain, compared to the control group. The largest reduction (80%) of nitric dioxide (oxidation number 4), characterized by high statistical significance, was also determined for mixture 3 (50% sawdust) in case of biofilter without water curtain. On the other hand, the other two mixtures were more effective in biofilter with a water curtain, and their effect on reduction was confirmed with statistically high significance. The statistical dependence, similar to the one described above, confirmed by the equally significant effectiveness of the mixture 3 in the biofilter without the curtain, and in case of the other two mixtures in the biofilter with the water curtain, was determined with the reduction of NO_x emissions. Analysis methane reduction demonstrated low reduction of this gas, confirmed by the lack of statistical significance between the use of mixed beds, and the water curtain in biofilters. Despite the lack of statistical confirmation, a small insignificant reduction in emissions of this type of gas was demonstrated by mixtures 2 and 3. CO_2 emission decreased due with statistical significance due to the use of mixture 1 (50% peat) and mixture 3 again (50% sawdust), both in biofilter without a water curtain, and in biofilter with a water curtain, wherein the effectiveness of mixture 1 and biofilter with a water curtain in reducing this gas was higher than in other deposits, reducing the emission of this gas by 20% compared to the control group.

Discussion

The emissions of gases in pig farm maintenance can be reduced in many ways. The most popular methods of reducing the emission of harmful gas admixtures involve nutritional solutions, the use of organic and mineral additives directly in the litter, as well as system and technology solutions (Osada & Fukumoto, 2001. The latter includes the use of air biofiltration in case of pig farms (Cloirec et al., 2001; Hendriks et al., 1998), as described in this study. The technology of pig housing is of considerable importance in using the latter method (Tymczyna et al., 2009, 2010; Aarnink, 1997). Mineral additives can act in two ways to reduce emissions. The first includes lowering the pH of faeces, which allows the inhibition of urease in the event of ammonia release or qualitative changes in active microflora in methanogenesis processes (Hartung et al., 2001). The second method comes down to the use of absorbency and hygroscopic properties of some minerals. Organic additives act similarly to absorbent minerals. Therefore, bearing in mind e.g. their absorbency and porosity in the mixtures of biofilter bed, it was decided to use cereal straw, sawdust, and peat (Nicolai & Janni, 2001). In addition, the use of a water curtain was also intended to bind and dissolve gaseous admixtures in water (McCrory & Hobbs, 2001).

When discussing and comparing the effectiveness of gaseous emission reduction when using a biofilter without and with the water curtain in fattening pig housing, high effectiveness of this method can be demonstrated in case of using most of the tested chemical compounds, yet it depends on the filter bed (Martens et al., 2001). After applying and comparing biofilters in the housing of fattening pigs, a slight reduction (0.022 kg/unit/year in a biofilter without a curtain and one with a curtain in case of mixtures containing 50% peat and 50% straw, respectively) or no VOC reduction by mixtures comprising filter beds and water curtain, is noteworthy. This problem may be partially related to the water insolubility of certain chemical compounds, although, according to literature, the complete elimination of such molecules would not be even advisable, because they often have informational functions for the species (Mayrhofer et al., 2006; Stuetz & Nicolas, 2001). However, the reduction of ammonia after the use of biofilters and beds is high and statistically confirmed, and it is determined by both the physico-chemical properties of the mixtures, as well as the very good water-solubility of this gas (McCrory & Hobbs, 2001). The reduction of low water-soluble nitric monoxide (oxidation number 2) was determined only for the biofilter with the water curtain and was not detected in the biofilter without the curtain. Apart from solubility, the main role in this case was played by mixtures 2 and 3 which significantly reduced the emission of this gas (0.005 and 0.002 kg/unit/year, respectively). The water biofilter has also proven to be more effective in NO_2 (oxidation number 4) reduction than the biofilter without water curtain which was associated with good solubility of this oxide in water, although the greatest emission reduction was observed in case of the biofilter without curtain and with mixture 3 (0.019 kg/unit/year). Similar reduction efficiencies and comparison of biofilter and blend efficiency applied to NO_x (0.42 kg/unit/year). Both types of biofilters were characterized by loweffectiveness in reducing CH_4 emissions and the most effective were mixtures2 and 3. In case of statistically confirmed reduction of CO_2 water biofilter – once again – and a mixture of 1 (128 kg/unit/year) proved to be more effective than the biofilter without a water curtain. In case of both biofilter types used in pig fattening, the selectivity of the filtration material deserves attention, which contributes to the reduction of individual compound groups. Mixture 1 (50% peat) provides the highest VOC reduction in biofilter without the water curtain (0.022 kg/unit/year) and CO_2 in both biofilter types (144 and 128 kg/unit/year). Mixture 2 (50% straw) reduces VOC in biofilter with curtain the most (0.022 kg/unit/year). NO_2 (0.047 kg/unit/year) and (0.052 kg/unit/year). Whereas the mixture 3 maximally reduces the NH_3, NO_2 and NO_x emission in the biofilter without the curtain, and NO in the biofilter with the curtain. This is due to the diversified composition of mineral mixtures and their physical and chemical properties, as well as indirectly its possibility of use by microflora as a nutrient. Literature sources directly mention the need to maintain a high C/N ratio, similarly to the material intended for composting (Choi et al., 2003).

Conclusions

Based on the obtained results, the following generalizations can be made concerning comparisons of pig gas emission reduction through the use of air biofilter without a water curtain and with a water curtain:

1. The use of biofilters without a curtain and with a water curtain to purify the air from fattening pig housing is an effective method of reducing environmental contamination.

2. The use of a biofilter with a water curtain to purify pig house air has proved to be more effective in reducing emissions of NO, NO_2, NO_x and CO_2 than using the biofilter without water curtain.

3. The best filtration properties in the biofilter without the water curtain were provided by mixtures containing increased amount of sawdust in their bed, while those with an increased amount of peat and straw were characterized by lower filtration efficiency.

4. The best filtration properties in the biofilter with the water curtain were provided by mixtures containing increased amount of straw in their bed, while those with an increased amount of peat and sawdust were characterized by lower filtration efficiency.

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Comparing the efficiency of reducing gas emissions from piggery using air biofilter and water curtain

SUMMARY

The aim of the study was to determine the possibility of reducing harmful gas emissions by filtering air ventilated from indoor pig housing. The experiment determined the groups of gas compounds in filtered and unfiltered air (control group) from pig housing as well as the efficiency of using an air biofilter with different mixtures that formed biofilter bed and an air biofilter with the same mixtures, equipped with a water curtain. The highest emission reduction for both biofilter types was obtained for ammonia (85%). The difference was highly significant for all mixture types. The biofilter with water curtain was more efficient in reducing NO_2, NO and CO_2 emissions. The best filtration properties were observed for the mixture whose bed contained more straw in the biofilter with water curtain, and for the mixture with more sawdust in the biofilter without water curtain.

Key words: GHG emission, air biofiltration, biofilter bed, pig housing, water curtain