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Removal of odorous compounds from poultry manure by microorganisms on perlite – bentonite carrier

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ABSTRACT

Laboratory-scale experiments were conducted using poultry manure (PM) from a laying hen farm. Six strains of bacteria and one strain of yeast, selected on the base of the previous study, were investigated to evaluate their activity in the removal of odorous compounds from poultry manure: pure cultures of *Bacillus subtilis* subsp. *spizizenii* LOCK 0272, *Bacillus megaterium* LOCK 0963, *Pseudomonas* sp. LOCK 0961, *Psychrobacter faecalis* LOCK 0965, *Leuconostoc mesenteroides* LOCK 0964, *Streptomyces violaceoruber* LOCK 0967, and *Candida inconspicua* LOCK 0272 were suspended in water solution and applied for PM deodorization. The most active strains in the removal of volatile odorous compounds (ammonia, hydrogen sulfide, dimethylamine, trimethylamine, isobutyric acid) belonged to *B. subtilis* subsp. *spizizenii*, *L. mesenteroides*, *C. inconspicua*, and *P. faecalis*. In the next series of experiments, a mixed culture of all tested strains was immobilized on a mineral carrier being a mixture of perlite and bentonite (20:80 by weight). That mixed culture applied for PM deodorization was particularly active against ammonia and hydrogen sulfide, which were removed from the exhaust gas by 20.8% and 17.5%, respectively. The experiments also showed that during deodorization the microorganisms could reduce the concentrations of proteins and amino acids in PM. In particular, the mixed culture was active against cysteine and methionine, which were removed from PM by around 45% within 24 h of deodorization.

1. Introduction

Animal breeding and the management of organic wastes entail the formation of odorous compounds that pose a serious problem for the health of livestock and workers as well as nearby residents. An odor can be defined as a sensation that occurs when an odorant (the chemical that happens to have an odor) impacts the sensory receptors in the nasal cavity (Schiffman et al., 2001). Odors are generated from the microbial degradation of biosolids including poultry manure, under the prevailing anaerobic or anoxic conditions, and major odorant precursors are proteins and carbohydrates (Aldin et al., 2011; Burgess et al., 2001; Higgins et al., 2008; Kuroda et al., 1996; Zhu, 2000). Poultry farms emit a large number of odorous and greenhouse gases including ammonia, methane, hydrogen sulfide, dimethylamine, carbon monoxide, carbon dioxide, mercaptans, volatile organic acids as well as phenolic compounds (Burgess et al., 2001). Odors generated from laying hen facilities belong to the most offensive, equal with the ones from pig farms. They can cause headaches, vomiting, loss of appetite and mental stress to residents living near poultry farms (Nimmermark, 2011; Kreis, 1978).

Malodorous compounds can be divided into four different chemical classes (Rappert and Müller, 2005b; Varel and Miller, 2001; Zhu, 2000): nitrogen-containing compounds, sulfur-containing compounds, volatile fatty acids, and aromatic compounds.

Ammonia is one of the main odorants found in the exhaust air from poultry breeding houses. Its main source is the decomposition of urine, uric acid and nitrogenous compounds like proteins and amino acids. The annual total nitrogen excretion from 100 chickens is in the range 81.3–128.9 kg, of which more than 10% is emitted as ammonia. Another 15–25% of the amount of N is emitted as ammonia during storage of manure (Petersen et al., 2007).

Volatilization of ammonia inside poultry houses can adversely affect the health of both workers and animals since ammonia

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irritates mucous membranes and respiratory tracts (Rylander and Carvalheiro, 2006; Ullman et al., 2004). Moreover, ammonia has a direct effect on the plants growing in the neighborhood of animal farms, and may cause eutrophication of water (Rappert and Müller, 2005b). Apart from ammonia, other nitrogen-containing odorants – volatile amines (dimethylamine, trimethylamine, diethylamine and triethylamine) and phyrazines – are found in polluted air from agricultural operations and from the food and chemical industries. The former are released during storage of fresh manure, particularly when the pH is lower than 6 (El Jalil et al., 2001; Rappert and Müller, 2005b).

Volatile sulfur compounds include hydrogen sulfide, methanethiol, dimethyl sulfide (DMS), dimethyl disulfide (DMDS), dimethyl trisulfide (DMTS), and carbon disulfide (CS_2). These compounds are produced by anaerobic microbial degradation of sulfur-containing amino acids such as methionine and cysteine (Aldin et al., 2011; Higgins et al., 2008); they are also present in some natural gases, crude oils and coal tars. Although sulfuric odorous compounds are generated in lower abundance than NH_3, they contribute substantially to the total odorous nuisance because their odor threshold limits are very low (e.g. 0.00209 mg/m^3 for methanethiol, 0.00219 mg/m^3 for diethyldisulfide) (Busca and Pistarino, 2003; Kim et al., 2007; Pinjing et al., 2001; Rappert and Müller, 2005a; Ruokojavi et al., 2001).

Volatile fatty acids (VFAs) represent major products of microbial decomposition of any organic wastes, and they are therefore regarded as useful indicators of offensive odors emanating from manure (Rappert and Müller, 2005b; Zahn et al., 1997). The nature of VFAs progresses from pungent odors of formic and acetic acids to the distinctly unpleasant and offensive odors of valeric and caproic acids (Zhu, 2000). Although the short chain acids are present in much higher concentrations and have larger volatility, the VFAs with higher carbon numbers demonstrate lower odor detection thresholds, thus they are more offensive in nature. Therefore a high concentration of VFAs in manure or compost may not necessarily cause high intensity of malodor (Zhu, 2000).

There are various ways to reduce odor nuisance arising during poultry farming. It is generally known that odors are mainly generated during decomposition of excess nutrients that are not digested by animals and are excreted in manure (Kreis, 1978). Hence, the first approach is manipulation of the diet, which improves the efficiency of nutrient retention by chickens, and decreases their excretion in uric acid and faeces (Feilberg and Sommer, 2013; Petersen et al., 2007). The reduction of protein content in the poultry diet and replacing them with synthetic amino acids can reduce N excretion by nearly 30% (Nahm, 2003). It was also reported that the inclusion of enzymes in the feed improves the biological availability of some specific nutrients by birds and, consequently, less nitrogen is present in fecal material (Petersen et al., 2007).

Biofiltration has been successfully applied in many countries to control malodorous, volatile organic compounds and other offensive exhaust gases in a wide area (Li et al., 1996). Two main types of biofiltration systems have been developed, i.e. biofilters and bioscrubbers. Literature reports a wide range of odor reduction by biofiltration, however, properly designed systems can achieve removal rates of more than 90% for most odorants (Lau et al., 1996; Ullman et al., 2004). Biofilters and bioscrubbers are mainly applied in pig housings with central ventilation ducts, whereas their application in poultry houses is limited due to high dust concentration in the ventilation air, which clogs fans and packing beds (Melse and Timmerman, 2009; Nahm, 2003; Ullman et al., 2004). Other disadvantages of biofiltration are large land requirements, excessive total costs, complicated maintenance and variable efficiency (Lau et al., 1996; Ullman et al., 2004; Woestyne and Verstraete, 2007).

Odor control by means of various chemical and biological additives has already been reported in the literature. Five main categories of additives can be distinguished (Woestyne and Verstraete, 2007):

- odorant oxidizing agents (e.g. permanganate or ozone);
- deodorants, which react with malodorous compounds, and neutralize them or inhibit their release;
- masking agents – compounds with a pleasant smell;
- digestive agents – mixed cultures of bacteria, other microorganisms and enzymes used to degrade odorous compounds in livestock
- miscellaneous chemicals – bacteriocides, disinfectants and plant extracts, which destroy microorganisms in livestock or inhibit enzymatic activity of microbes responsible for odor formation.

Mineral additive: magnesium hydroxide and calcium carbonate with or without a carrier medium, was successfully applied to poultry litter in an amount of 5–25% by weight. A consequential effect was the reduction of ammonia emissions from fresh and stored manure by 90%, and the main product of that action was magnesium ammonium phosphate known as struvite (Champ and Bakewell, 2004). Moore et al. (1995) conducted a laboratory study to determine the effect of chemical amendments on ammonia volatilization from poultry litter using the following chemicals: calcium hydroxide, $Al_2(SO_4^-)_3 \times 18H_2O$ (alum), alum + $CaCO_3$, ferrous sulfate, and one commercial product. The results of that study showed that the addition of alum to poultry litter dramatically reduced NH_3 volatilization resulting in higher total and soluble nitrogen in the litter. Luo and Lindsey (2006) found that the addition of zeolites to the bark medium in the biofilter could enhance odor-removal performance. Chemical and microbial amendments including tap and salt water, treated manure, soybean and essential oil as well as randomly selected commercial biopreparations were tested by Kim et al. (2008) in pig buildings. The treatments of salt water, digested manure and microbial additives were observed evidently to decrease the concentration of ammonia, while for sulfuric odor compounds, only a spray of essential oil had a positive effect. According to the authors, the precise mechanism of how the above additives reduce each of the odorous compounds is not well documented.

Therefore the aim of the following study was to evaluate the effectiveness of the removal of volatile malodorous compounds from poultry manure by means of a mixed culture containing microorganisms isolated from various natural environments carried on mineral carriers (perlite and bentonite). According to the authors' best knowledge, the use of active aerobic microbes carried on perlite and benthonite for deodorization of poultry manure has not been described in the literature yet.

2. Materials and methods

2.1. Poultry manure

Solid poultry manure samples were collected from a non-litter poultry farm in Zgierz (Poland) at which 50,000 laying hens are kept.

2.2. Chemical analysis of poultry manure

All the samples (poultry manure controls, and the experimental samples with mixed culture during the deodorization