Potentials for biological treatment of odorous gaseous emissions from poultry farming facility in Russia

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Abstract. One of many environmental problems of poultry farming enterprises is the emission and spread of unpleasant smell over long distances. The odours significantly reduce the living standards of the population near the poultry farm. Odour occurrence in poultry houses is caused mainly by decomposition of bird waste such as faeces, urine, feathers mixed with bedding material and dust. The percentage of ammonia was the highest (95 %), methane and dust were significantly lower (3 % and 2 %, respectively). In the paper, we described a biological air filtration unit bioscrubber and estimated its economic efficiency.

1. Introduction

Unlike the majority of foreign industries, where poultry farming is concentrated on many small farms, and slaughtering is carried out at large enterprises, in Russian practice, cultivation, slaughtering, and production of poultry products are mainly concentrated within a single unit – at broiler poultry factories. In recent years, there has been an increase in their capacity. In the late 80s of the XX century in the Russian Federation there were only three poultry processing facilities with capacity of 40 tons per shift (the average capacity of poultry processing was 7.8 tons per shift in the country). Nowadays, there are several dozens of such facilities. Specialized broiler poultry factories and poultry associations produced in 2018 more than 70% of all domestic poultry meat production in all forms of management, and the 10 largest of them – 50% of this amount [1].

Industrial methods of animal farming are characterized by a high living concentration and density of animals and poultry. There have been releasing a significant number of different harmful and odorous substances as a result of the life activities of animals and poultry. The main sources of pollution from animal farms into the environment are ventilation emissions consisting of dust, microorganisms, odorous and odourless gaseous harmful substances [2, 3].

There are three main areas of odour emissions and their contribution: aviaries (30 %), manure storage buildings (20 %), and manure application to fields (50 %) [4]. Odours are being generated during fermentation when bedding, urine, excreta, and food remain decomposed, as well as during breathing, digestion, and evaporation from the animal's skin [5]. The emission of odour depends on many factors, including species of animal/birds, animal/birds diet, housing system as well as methods of manure storing and application, and weather conditions [6]. Odour pollution can even affect areas far from emission sources.
Dust is often considered to be the carrier of bad smelling substances. It participates in the emission and transport of odours that occur due to odorous compounds and odour causing microorganisms that are adsorbed on dust particles.

The main bad smelling substances produced in poultry farms are ammonia, hydrogen sulphide, as well as classes of organic compounds such as amines, sulphides, volatile fatty acids, phenols, mercaptans, alcohols, and carbonyl [4]. In addition, CO₂-free greenhouse gases (e.g., methane (CH₄) and nitrous oxide (N₂O)) and other substances of organic origin are also classified as unpleasant smelling substances. Ammonia-related hazards include poisoning of living organisms, acidification of soil and water, and high nitrate levels in drinking water. Greenhouse gas emissions increase global concentrations of these gases in the atmosphere, which on average leads to global warming [5]. In recent years, emissions of unpleasant odours from livestock buildings and manure management on land have been increasingly considered as unpleasant phenomena in densely populated countries as livestock production has expanded and more rural dwellings have been built in traditional agricultural areas [4-5].

A person can easily detect the appearance of an unpleasant odour in the atmospheric air. The odour causes him a sense of discomfort and irritation. When a single substance gives an odour, its reflex effect on a person is taken into account when setting the MAC for a given compound. However, in many cases, a complex mixture of substances but not an individual one is forming the odour. In addition, it is often impossible to identify specific odour compounds with established MACs. In such a case, developed countries do not control the emissions of individual odorous substances, but the odour as a whole. Odour control activities include a wide variety of activities, including public surveys, analysis of public complaints, inspections, etc.

Until recently, there has been little attention in Russia to the problems of odour emissions from industrial facilities. However, the growing number of complaints from the population [7, 8], who do not want to live in uncomfortable conditions, forces the state authorities to take decisive measures, in particular, in the coming years the St. Petersburg government plans to introduce a system of odour control and rationing [2]. At the same time, the most advanced emitters of odorous substances are already aware of the importance of this problem and the need for a quantitative study of odour emissions from sources owned by the enterprise.

Several authors [7, 9, 10] consider the problem of odour control and research of the problem and suggest possible ways to solve the problem of regulation and calculation of odour from emissions of industrial enterprises.

At the same time, at the federal level in the Russian Federation in 2015 there was approved a standard GOST 32673-2014 “Rules for setting standards and controlling emissions of odorous substances into the atmosphere”. The document is an accurate translation of the main EU standard that establishes the concepts, terms, and definitions associated with the normalization of odours.

Thus, it can be concluded that the problem of unpleasant odour emissions in Russia will develop in the coming years. And the introduction of technologies to purify the air from bad smelling substances may become widespread. This, in turn, will give an impetus to the development of technologies, installations and methods of purification of gas and air emissions, since modern standards and methods are aimed at treatment of a specific type of substance or a specific pollutant.

2. Methods
The conducted research consisted of several stages. During the first phase, the researcher conducted a literature review of available technologies for controlling smelly emissions. Afterwards, the author focused on the selected method of biological air purification, as the sources indicate extraordinary efficiency of purification. The cost-effectiveness of a biological scrubber plant in two cases was then calculated as an attempt of evaluation.

It has been established that there are several categories of technologies for removing bad smelling substances. The first is a group of technologies to prevent or reduce the resulting volume of bad smelling substances [11].
Prevention or reduction of odour and dust formation is an optimal solution and will reduce the need for other categories of odour control technologies. Odour prevention can potentially be achieved by manipulating nutrition or changing the conditions to reduce the activity of micro-organisms that produce unpleasant odours (by using bedding/feed additives or controlling humidity, temperature, pH, or bedding aeration). However, in large poultry farms with annual turnover, most of such manipulations are found to be ineffective.

The second category is technologies of capture and destroying odours before they enter the atmosphere. Such technologies that capture, contain, or treat odours and dust before they are released to the atmosphere work on the principles of biological, chemical, or physical treatment. Biological processes are used in technologies such as biofilters and biocrubbers, where the microbial action converts odorous compounds into less odorous ones. Chemical processes are used in technologies such as chemical scrubbers or ozone treatment systems, where chemicals in a cleaning fluid remove or convert odorous compounds from an air stream. Physical processes include thermal or catalytic incineration, UV treatment, dry or wet filtration (for dust). These processes either remove the pollutant or use energy to destroy or convert pollutants.

One of the ways to neutralize exhaust gases from numerous and dissimilar harmful chemical compounds is its thermal treatment – combustion. Many foreign companies performed it by means of afterburning of pollutant gases when a high temperature of the process (700–1000°C) was reached.

The literature describes several cases of using the incineration method for treatment of poultry farms’ waste gases. The annual fuel (natural gas) consumption in both cases was not less than 2.0 million m³ [11]. Moreover, the envisaged flue gas recirculation system through the drying drum ensured complete deodorization of the flue gases only if the evaporating moisture capacity of the unit is reduced more than twice.

Analysis of sources revealed several disadvantages of this method:
- during fuel combustion (especially if temperature conditions are not observed), toxic benzene(s) pyrene and nitrogen oxides are formed;
- the degree of transformation of organic compounds 97-99 % is achieved at temperatures of 1000 °C, which requires significant energy and/or fuel consumption;
- this method has a limited application and is used only with characteristic waste gases due to catalyst poisoning with certain compounds.

Currently, ozone devices are used at poultry farms mainly for disinfection of products or indoor air. However, there are installations for neutralization with ozone of bad smelling industrial exhaust gases, for example, containing methyl methycaptopropine aldehyde, acetaldehyde, formaldehyde, and other products of organic synthesis, as well as gases containing sulphur compounds (sulphur carbon and hydrogen sulphide). The possibility of application of ozonation plants for ventilation air purification in several industries (animal husbandry, poultry farming, and production of artificial fibres) has also been considered.

The disadvantage of the method of treatment of waste gases with the help of ozone is its high cost – the plant will be quite expensive in operation. In addition, a number of authors point to the potential effect of ozone on the bronchial tree of a poultry tree, which may cause the rejection of the poultry house batch and loss of revenue [12].

In a typical biofiltration system, a moist, polluted air stream continuously passes through the moist, porous bedding material to which suitable microorganisms are naturally immobilized and organized as a thin water layer of biofilm surrounding the bedding material particles. As the air passes through the substrate, gaseous pollutants are transferred, and the air enters the biofilm together with the pollutant substances. The pollutants are then decomposed by acclimatized microorganisms colonizing the biofilm, which include them in the biomass of microorganisms or use them as energy sources, while oxygen for biological activity of microbes is directly supplied by the air stream [6]. At the same time, inside the biofilm there is diffusion and absorption of necessary inorganic nutrients such as available forms of nitrogen, potassium, and phosphorus.
The end products of aerobic biodegradation are water, carbon dioxide, and new biomass. Inorganic products can also form when air pollutants such as sulphur, nitrogen, or chlorine are present. The overall process of aerobic biodegradation can be represented as follows, in the case of pollutants containing carbon, hydrogen, and, sometimes, oxygen:

\[
\text{Organic pollutant} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{Heat} + \text{New biomass} \tag{1}
\]

If chlorine or sulphur atoms are also present, HCl and H_2SO_4 will form in the same way as the final product.

The three main biological systems used so far to purify industrial emissions are biological scrubbers (biocrubbers), simple biofilters, and drip biofilters. These air purification systems can be roughly grouped into bioreactors that use microorganisms that are freely dispersed throughout the aqueous phase (bioscrubbers) and bioreactors that use microorganisms immobilized on solid substrates (simple biofilters and drip biofilters). In addition, biocrubbers and drip biofilters work with a continuously circulating aqueous phase, while in simple biofilters the aqueous phase is stationary.

The biological scrubber consists of two functional parts: scrubber and regeneration. In the scrubber plant (adsorbent), soluble pollutants from the air are transferred to the atomized aqueous phase and can be partially oxidized (by microorganisms suspended in the recirculating liquid phase). The polluted aqueous phase containing dissolved air pollutants is then transferred to an aerated reactor with a stirrer (regeneration plant) similar to the activated sludge plant, where pollutants are decomposed by aerobic microorganisms freely suspended in the aqueous phase [13]. In a bioscrubber, air and water flows usually go against the current. To guarantee biological activity, a nutrient solution can be added to the aqueous phase. If the aqueous phase is the waste water of a reactor with activated sludge, then, naturally, there may be a sufficient amount of biogenic elements in the medium. The regenerated suspension is continuously processed into the upper part of the scrubber plant, thus increasing the process efficiency. A typical biological treatment system is shown in Figure 1 [14].

![Figure 1. Schematic representation of bioscrubber.](image)

3. Results
The research was conducted according to the data of Poultry Farm Severnaya. The company was founded in 1997 and is currently one of the largest poultry processing facilities not only in the Leningrad region, but also in the Russian Federation. The main part of the goods offered by the poultry farm “Severnaya” is chilled poultry, but there are also frozen broiler chickens. According to available data, in 2014 alone, the company produced 171,000 tons of products, which is 5% of the production of chicken meat throughout Russia. The birds are maintained in the big multilevel cages (Fig. 2) in the poultry houses united in three extended broiler shops. Each of them is equipped with a ventilation system.
Figure 2. Housing conditions for birds.

The airborne gaseous pollutants released into the house were ranked by their water solubility (Table 1). Other pollutants are liquids or solids dissolved in the air, such as methanol, hydroxybenzene, propane, and caproic acid. However, they also contribute to the formation of an unpleasant odour, as each substance has its own sharp scent.

Table 1. The solubility of some air contaminants.

| Substance         | Solubility coefficient, gram per litre | Gross emission, tons/year |
|-------------------|---------------------------------------|---------------------------|
| Methylamine       | 757                                   | 0.006                     |
| Ammonia           | 685                                   | 41 600                    |
| Hydrogen sulphide | 2.59                                  | 0.020                     |
| Methane           | 0.33                                  | 1 400                     |

Analysing the composition of pollutants found in the exhaust air of poultry houses, we can conclude that the gaseous pollutants are well and poorly soluble gases. Well soluble gases include methylamine and ammonia. The specific amount of ammonia in emissions is the highest among all other pollutants - 46.1 tons per year. Mercaptan and hydrogen sulphide are represented in small amounts and their solubility factor is low. Methane is the least soluble gas among the presented ones; nevertheless, 1.4 tons per year were emitted.

Among liquid pollutants we can mention methanol with good solubility; however, the total amount of emitted methanol is small – 0.0142 tons/year.

It should also be noted that the gaseous emissions of the Severnaya Poultry Farm include grain, fur, and feed dust, which means that it is necessary to install an air pre-filtration system to extract dust particles that can destroy the microbial community of the biological filter and prevent its further operation.

Considering the percentage of bad smelling pollutants, we can conclude that the largest volume belongs to ammonia emissions (95 %), the next place is occupied by methane emissions (3 %) (Fig. 3).

Based on English-language literature and data found on the websites of foreign manufacturers, the calculation of capital costs and net annual savings for bioscrubber plants was made [15, 16]. According to information on sites, the total amount of investments (Iₜ) made by the company for a drip biofilter plant is approximately 250 000 €, which is 19 611 225 roubles.
Figure 3. Proportion of contaminants, tons/year.

We model two situations, in which the company may find itself in connection with the installation of the bioscrubber model.

We calculate the net annual savings (B) based on the amount of emissions as well as the percentage of purification from gaseous emissions. We take the percentage of air purification as 80% and this will be the efficiency of the bioscrubber. At calculation we consider that according to 2020 standards the rate of payment for emission of harmful substance into air is multiplied by 1.08. In addition, one should take into account the benefit that the company will get from preventing penalties. If the company checks for non-compliance with the regulations (emissions of pollutants), the poultry farm can be fined at any time. Net annual savings are \( B = 63,916 \) roubles per year. Then the payback period (PP) is calculated as:

\[
PP = \frac{I_o}{B}
\]

and PP is equal to 309.5 years.

The second scenario toughens sanctions for the poultry farm. The federal Law of Environmental Protection states that in case of non-compliance with the reduction in the volume or mass of pollutant emissions within six months after the deadlines defined in the environmental protection plan or environmental efficiency improvement program, the fee will be calculated for the corresponding reporting periods for the volume or mass of pollutant emissions using the coefficient 100. The recalculation of net annual savings showed that in this case, using this factor, the indicator \( B = 6,391,642 \) roubles was used.

Then the payback period of a bioscrubber installation will be sharply reduced: \( PP = 19,611,225/6,391,642 = 3.1 \) years.

4. Conclusion

The following odorous compounds have been found in poultry farm emissions: methylamine, ammonia, hydrogen sulphide, and methane. Caproic acid, methanol, and hydroxybenzene were found in smaller volumes. Odour occurrence in poultry houses is caused by decomposition of bird waste such as faeces, urine, and feathers mixed with bedding material. An additional problem with odour spreading is dust, as it participates in the transportation of odour. The percentage of ammonia was the highest (95%), methane and dust were significantly lower (3% and 2%, respectively). The biological air filtration unit bioscrubber for purification of gases was chosen. The necessary technological parameters of the air biofiltration unit were calculated. Ecological and economic efficiencies of bioscrubber were also calculated. Under certain conditions, the payback period of a bioscrubber could be 3.1 years. In a poultry farm, a bioscrubber is environmentally friendly. However, the economic benefit to the plant will be minimal, while the installation costs are very high. In the future, it is planned to continue work on the economically more profitable introduction of a bioscrubber at livestock enterprises.

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