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Technology for reducing gas emissions from livestock farms

Nikita B. Bondarenko[1]✉, Nadezda V. Kondakova[2], Sergey V. Starovoytov[3], Denis A. Butko[1]

[1]Don State Technical University, Rostov-on-Don, Russian Federation
[2]Platov South-Russian State Polytechnic University (NPI), Novocherkassk, Russian Federation
[3]Rostov State Transport University, Rostov-on-Don, Russian Federation
✉nikbond@mail.ru

Abstract. The study provides an overview of methods for neutralizing pollutants from emissions from livestock facilities. The principal possibility of gas purification with the use of sorbents based on natural materials is presented. Pilot tests were conducted on the territory of an operating livestock farm in the Republic of Kalmykia. During the experiment, the type of sorption loading of the biofilter varied, which made it possible to assess the basic requirements, engineering fundamentals, principles of operation, applicability, economic efficiency and potential failures of the proposed method.

Keywords: air pollutants, foul-smelling substances, emissions from livestock farms, biosorber

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Технология снижения газовых выбросов животноводческих ферм

Н.Б. Бондаренко[1]✉, Н.В. Кондакова[2], С.В. Старовойтов[3], Д.А. Бутко[1]

[1]*Донской государственный технический университет, г. Ростов-на-Дону, Российская Федерация*
[2]*Южно-Российский государственный политехнический университет (НПИ) им. М.И. Платова, Ростовская область, г. Новочеркасск, Российская Федерация*
[3]*Ростовский государственный университет путей сообщения, г. Ростов-на-Дону, Российская Федерация*
✉nikbond@mail.ru

Аннотация. В исследовании представлен обзор методов обезвреживания загрязняющих веществ в выбросах от объектов животноводческих хозяйств. Представлена принципиальная возможность очистки газов с применением сорбентов на основе природных материалов. Опытные испытания проводились на территории действующей животноводческой фермы в Республике Калмыкия. В ходе эксперимента варьировался тип сорбционной загрузки биофильтра, что позволило оценить основные требования, инженерные основы, принципы работы, применимость, экономическую эффективность и потенциальные отказы предложенного метода.

Ключевые слова: воздушные поллютанты, дурнопахнущие вещества, выбросы животноводческих ферм, биосорбер

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In the last decade in the territory of Russia there has been quite a dynamic development of agricultural activities, production of products from plant and animal raw materials. The emergence of a wide range of large agro-industrial complex and highly productive processing enterprises implies, first of all, sources of increased technospheric hazard, where the main negative factor affecting the state of the environment and public health [1; 2] are air and water pollutants.

The most harmful air pollutants entering the atmosphere during production cycles of agricultural enterprises are greenhouse gases[1] with the main composition of carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (NO), nitrogen dioxide (NO_2), ammonia (NH_3), sulfur compounds and a significant amount of dust (bioaerosols).[2] An important factor is the presence of odoriferous substances formed at livestock and poultry complexes during animal housing, cleaning and storage of poultry litter and manure.[3]

Particular attention should be paid to the fact that the vast majority of modern production processes in agriculture and processing of animal products still use open technological cycles that do not exclude the release of air pollutants into the environment. This tendency is observed even in economically developed countries, where great attention is paid to the development of waste-free processes technologies with integrated processing or removal of by-products in closed production cycles.[4]

Reviewing the main methods of purification and neutralization of agricultural waste gases activities, first of all it is worth paying attention to their chemical and disperse composition. The most common types of equipment for capturing dust particles and liquid droplets are cyclone or fabric (sack) filters, where the removal of pollutant particles occurs under the action of centrifugal force and further bunkering or removal of the accumulated mass by back-blowing. This method of filtration is quite effective and easy to maintain but does not allow to reduce MPC of some air pollutants to acceptable levels due to the possibility of capturing only large particles (40…1000 microns).

Scrubber wash devices are widely used, as they are characterized by effective purification and capture of fire hazardous dusts and in those cases when in parallel it is necessary to purify the air from toxic impurities and vapors. One of the common devices of this type is a rotocyclone, where the mixture of contaminated air under pressure created by the vortex flow passes through a layer of water in which heavy particles are precipitated and then removed. However, devices of such technological principle have a number of significant disadvantages, limiting the area of their application: formation of a significant mass of sludge with subsequent removal and transfer, formation of condensed deposits in gas ducts and the need to supply recycled water to the catcher.

[1] Convention on Long-Range Transboundary Air Pollution. Guidance document on control techniques for emissions of sulphur, NOx, VOCs, dust (including PM 10, PM 2.5 and black carbon) from stationary sources. Informal document No. 2. Provisional Agenda Item 5. Draft guidance documents to the revised 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. Working Group on Strategies and Review, Fiftieth session, 10–14 September 2012, p. 268.
[2] *Environmental protection in Russia. 2020: Stat. sb./Rosstat*. p. 34–38. Moscow, 2020. 113 p.
[3] *Report on the inventory of anthropogenic greenhouse gas emissions of the Republic of Khakassia for 2019. Stat. sb.* Minprirody of Russia. Moscow, 2020. p. 34–37.
[4] *European Commission. Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs*. 2013. p. 32–39; 183–197.

Alternative solutions for air purification are adsorption and absorption systems, where the absorption of the pollutant is carried out by the volume of another body. These methods are the most common and are used for removal of insoluble (or poorly soluble) pollutants in water or absorption of pollutant substances by the surface layer of a solid body (activated carbon, aluminogels, silica gels, alumina, etc.). Technological units of this type allow selective removal of a wide range of pollutants, such as: sulfur dioxide (SO_2), hydrogen sulfide (H_2S), nitrogen oxide (NO), nitrogen dioxide (NO_2), ammonia (NH_3), as well as various hydrocarbon compounds (CH_4). Moreover, the above methods allow to achieve not only high ecological value, but also economic, because they allow to return to the air exchange system an increased volume of vapors of volatile solvents, which is especially relevant when used in agricultural production of closed type (poultry farms, barns, etc.). The disadvantages of such systems include financial disadvantage in the purchase of expensive adsorbents and logistical difficulties of delivery to remote rural areas.

Analyzing the profile data of thematic literature sources, the use of organic loadings for absorption air purification is a promising direction, implying not only economic benefits, but also improving the environmental friendliness of technological purification processes [4; 5].

Gas-phase biofilters are biological reactors that use microorganisms colonizing a porous medium to decompose pollutants from the air stream. Biofilters have the potential to treat large volumes of air pollutants at low concentrations, which is common in agricultural waste gas emissions. Ammonia is removed from the air stream by adsorption on the solid media of the biofilter (also, by irrigation of the load, liquid absorption) and then oxidized by microbial nitrification, which is the aerobic conversion of NH_3 to nitrite (NO_2^-) and nitrate (NO_3^-) [5]. Poor oxygen penetration into the biofilter media leads to potential oxygen-free/anaerobic microbial metabolic conditions that will inhibit nitrification and increase the likelihood of denitrification. The use of straw as the basis for sorbent loading, minimizes these risks.

Considering a separate object of technospheric hazard, the team of authors of this article conducted a study on purification of gas emissions from a livestock farm located in a semi-desert zone in the Republic of Kalmykia. The experimental part was based on the application of the previously developed experimental unit [6], where silicon-containing rocks (bentonite and diatomite), as well as pre-prepared wheat straw of local origin were used as absorber loading. The use of these materials is explained by the efficiency of pollutant removal, low cost and high sorption capacity [7].

The model plant is a tank simulating a receiving chamber-lagoon for storage of cattle waste. Inside the model tank there is a regulated air blower, which allows to discharge a directed air flow with a velocity $\geq$ 1.5…2 m/s, which is almost identical to the lagoon chambers according to the results obtained on-site. The parallel experiment involved the passage of a contaminated air stream through three models of absorbers with sorbent loading of different materials. The general view of the parallel experiment and installations is shown in Figure 1.

Figure 1.Installations at the time of measurement
Source: author's photo.

The used models of biosorbers with organic sorbent loading is a 200 ml container, where the prepared straw with a volume of about 55 cm^3 is placed. To select the most effective loading, a parallel experiment was conducted on three models with different variants of working raw materials, where the initial wheat straw was mixed with thermally modified siliceous rock of one of the deposits of the Rostov region ($D \approx 1$ mm, $V = 16$ cm^3), as well as ash of the same straw, carbonized at a temperature of about 250…300 ^{o}C ($V = 16$ cm^3):

1. Treated wheat straw ($V = 55$ cm^3).
2. Treated wheat straw + thermally modified siliceous rock ($V = 55$ cm^3 + 16 cm^3 = 71.5 cm^3).
3. Treated wheat straw + straw carbonizate ($V = 55$ cm^3 + 16 cm^3 = 71.5 cm^3).

Biosorbers were hermetically connected to the plants, where the volume of air flow with pollutants passed through the adsorbing load. Further, at the outlet from the conductive chambers at the extreme points of the installations, silicone hoses were installed for direct connection to SI (gas analyzers). The general view of biosorbers with organic loading at the time of measurement is presented in Figure 2.

Figure 2. General view of organic-loaded biosorbers
Source: author's photo.

Cattle and small ruminants' waste mixed with rainwater ($V = 2.5$ l) was sampled from the receiving chamber-lagoon as a solution to simulate the release of airborne pollutants.

To measure the concentration of pollutants in emissions from the model tanks we used gas analyzers Eco-Intech ELAN and Kolion 1-B, which have valid certificates of verification of measuring instruments.

Table 1 presents the initial concentrations of gas emissions from the model solution compared to the norms of SanPin 1.2.3685-21 in mg/m^3 (as average results of three parallel measurements).[5]

[5] Resolution of the Chief State Sanitary Doctor of the Russian Federation "On approval of sanitary rules and norms SanPiN 1.2.3685-21 "Hygienic norms and requirements to ensure the safety and (or) harmlessness to human factors of the environment" (together with "SanPiN 1.2.3685-21)" from 28.01.2021 № 2. *Collection of Legislation of the Russian Federation*.

Table 1. **Comparative indicators of the composition of gas emissions of the model solution and MPC according to SanPin 1.2.3685-21**

No.	Indicator to be determined (gas)	Unit of measurement	Result of measurements	MPC m.r.
1	CO (Carbon oxide)	mg/m^3	7.03	5
2	NO (Nitrous oxide)	mg/m^3	0.005	0.4
3	NO_2 (Nitrogen dioxide)	mg/m^3	0.553	0.2
4	H_2S (Hydrogen sulfide)	mg/m^3	0.35	0.008
5	SO_2 (Sulphur dioxide)	mg/m^3	0.49	0.5
6	NH_3 (Ammonia)	mg/m^3	11.,0	0.2

Source: compiled by the authors.

According to the obtained data of measurement of initial concentration of pollutants (Table 1), it is obvious that some indicators significantly exceed the MPC norms (according to the requirements of SanPin 1.2.3685-21), so the team of authors of this article decided to search for the most optimized composition of absorption loading in three different versions.

This experiment was based on three parallel measurements of treated gas emissions, where the measurement of pollutant concentration was performed in 5 control time segments with intervals of 30 minutes. This methodology allowed to establish the most effective organic composition of the feedstock used in biosorbers. From the results of the control measurements at the 5th control time point (Table 2), it was possible to reveal dynamics (removal of pollutants is expressed in %) on essential decrease of concentration almost for all indicators, where only insignificant increase of emission of air pollutants of only one group is an exception.

Table 2. **Results of 3 comparative gas emission measurements (with % removal) obtained using biosorbers with mixed packed beds**

No.	Determinable indicator (gas)	Measurement unit	Result of measurements			MPC m.r.
			Straw + bentonite + coal	Straw + bentonite	Straw + coal	
1	CO (Carbon oxide)	mg/m^3	4.98 ***+29.2%***	4.01 ***42.9%***	4.92 ***30%***	5
2	NO (Nitrogen monoxide)	mg/m^3	0.041 ***+4.1%***	0.016 ***+1.6%***	0.015 ***+1.5%***	0.4
3	NO_2 (Nitrogen dioxide)	mg/m^3	0.000 ***100%***	0.091 ***83.5%***	0.000 ***100%***	0.2
4	H_2S (Hydrogen sulfide)	mg/m^3	0.00 ***100%***	0.08 ***77.1%***	0.00 ***100%***	0.008
5	SO_2 (Sulphur dioxide)	mg/m^3	0.31 ***36.7%***	0.39 ***20.4%***	0.24 ***51%***	0.5
6	NH_3 (Ammonia)	mg/m^3	0 ***100%***	7.0 ***63.6%***	0 ***100%***	0.2

Source: compiled by the authors.

Based on the final data of parallel measurements presented in Table 2, the rationality of using a mixture of selected organic materials is obvious. Percentage ratio of values of removed substances (Table 1) indicates almost complete purification of the whole volume of polluted air passing through the absorbers installed on the model simulating pollutants emission from the receiving chambers-lagoons. Insignificant increase of nitrogen monoxide (NO) and carbon monoxide (CO) emission can be related to the possible filling of adsorption pores (sorbent energy consumption), since the use of such materials in aggressive environments leads to a rather rapid decrease in adsorption characteristics [8].

The results obtained during the above-mentioned experimental parallel experiment allow us to conclude that the selection of mixed organic packed beds for biosorbers is successful and correct. An additional additive factor is the efficiency of this type of beds (based on the data of Table 2), which is almost close to the mark of complete removal of the specified groups of air pollutants, which allows us to identify further prospects in the development of sorbing materials from agricultural wastes and silicon-containing rocks. The subject of using such types of sorbents in conditions of real objects of industry and agriculture requires further research on technological efficiency.

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Bio notes:

Nikita B. Bondarenko, Post-graduate Student of Water Supply and Sanitation Department, Don State Technical University, 1 Gagarina Sq., Rostov-on-Don, 344010, Russian Federation. E-mail: nikbond@mail.ru

Nadezda V. Kondakova, Graduate student of Department of Water Management, Engineering Networks and Environmental Protection, Federal State Budget Educational Institution of Higher Professional Education "Platov South-Russian State Polytechnic University (NPI)", 132 Prosvecheniya St., Novocherkassk, 346428, Russian Federation. E-mail: kondakova.nadya.v@yandex.ru

Sergey V. Starovoytov, Candidate of Technical Sciences, Associate Ph. D., Associate Professor Chair: "Heat and power engineering on railway", Rostov State Transport University (RSTU), 2 Rostov Rifle Regiment of the People's Militia Sq., Rostov-on-Don, 344038, Russian Federation. E-mail: se.starovoytov@yandex.ru

Denis A. Butko, Candidate of Technical Sciences, Head of the Department of Water Supply and Sanitation, Don State Technical University, 1 Gagarina Sq., Rostov-on-Don, 344010, Russian Federation. E-mail: den_111@mail.ru