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SANITATION OF AIR IN LIVESTOCK FACILITIES

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The health of productive animals is directly dependent on their housing conditions and utilization. The environment of livestock biocenoses must comply with current standards and be safe from a sanitary standpoint. Achieving this is only possible with the implementation of highly efficient disinfection technologies in production. A pressing issue today remains the development of innovative devices and methods for air decontamination in livestock facilities. Device construction was based on the results of patent research and a comparative analysis of existing analogs and prototypes. The effectiveness of disinfectants was assessed in accordance with applicable regulatory documents. As a result of the work carried out, a device was developed for air purification in livestock facilities. It features two-stage biological-droplet filters, sedimentation chambers, water supply regulation valves, water recirculation pipeline systems, and systems for water supply and drainage. A device for air sanitation in livestock facilities was also developed, which provides simultaneous air ionization and ultraviolet irradiation. This device includes a source of ultraviolet radiation and a water drainage and purification system for processed water. Additionally, methods for deodorization, aerosol disinfection, and fumigation of the air environment in livestock facilities were created. These methods involve the use of innovative disinfectants from various chemical groups under appropriate application regimes. They meet modern requirements for livestock management and are effective, environmentally safe, economical, and easy to use. The prospect of further research lies in improving technological approaches to decontaminating livestock environments.

Keywords: *facilities, air, device, disinfection, disinfectant.*

САНАЦІЯ ПОВІТРЯ ТВАРИННИЦЬКИХ ПРИМІЩЕНЬ

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Здоров'я продуктивних тварин має пряму залежність від умов утримання та використання. Середовище тваринницьких біоценозів повинно відповідати діючим нормам та бути безпечним в санітарному відношенні. Це все можливе лише при впровадженні у виробництво високоефективних технологій дезінфекції. Актуальним питанням на сьогодні залишається розробка інноваційних пристрої та способів знезараження повітря тваринницьких приміщень. Конструювання пристроїв проводили за результатами патентного пошуку та порівняльного аналізу існуючих аналогів та прототипів. Оцінку ефективності застосування деззасобів проводили відповідно до чинних нормативних документів. За результатами проведеної роботи розроблено пристрій для очищення повітря тваринницьких приміщень з двоступеневими біологічно-крапельного типу фільтрами, відстійниками, вентилями регулювання подачі води, системами трубопроводів рециркуляції води та системами трубопроводів водопостачання та відведення. Розроблено пристрій для санації повітря тваринницьких приміщень, який забезпечує проведення одночасно аероіонізації та ультрафіолетового опромінення повітря та містить джерело ультрафіолетового опромінення та систему водовідведення і очищення відпрацьованої води. Також розроблені способи дезодорації, аерозольної дезінфекції та фумігації повітряного середовища тваринницьких приміщень. Дані способи передбачають застосування інноваційних знезаражуючих засобів з різних хімічних груп за відповідних режимів застосування. Вони відповідають сучасним вимогам щодо організації тваринництва, є ефективними, екологічно безпечними, економічними та простими при застосуванні. Перспектива подальших досліджень полягає у вдосконаленні технологічних підходів знезараження об'єктів тваринництва.

Ключові слова: *приміщення, повітря, пристрій, дезінфекція, дезінфектант.*

Introduction. An important aspect of ensuring high animal productivity and obtaining high-quality animal-derived products is maintaining sanitary and hygienic conditions for the livestock (Paliy A. P. et al., 2018; Dallago G. M. et al., 2021). Housing a large number of animals within a limited area creates epizootic risks for the spread of pathogenic and opportunistic microflora among susceptible livestock. Therefore, one of the main practices in any livestock farm is the implementation of comprehensive veterinary and sanitary measures based on the use of modern disinfection technologies (Shkromada O. et al., 2019; Ventura G. et al., 2021; Moje N. et al., 2023).

To eliminate microbiota, various methods are used, involving both chemical (Addie D. D. et al., 2015; Paliy A. et al., 2024; Tyski S. et al., 2024) and physical (Memarzadeh F., 2021; Sun Y., et al., 2023) agents. Commonly used chemical compounds in production include chlorine-based, aldehyde-based, oxygen-based preparations, and others (Paliy A. P., 2018; Curran E. T. et al., 2019; Artasensi A. et al., 2021). Despite their high bactericidal properties, chemical compounds are characterized by several negative effects, such as toxicity and carcinogenicity (Frentzel H. et al., 2013). Moreover, not all currently available antimicrobial agents are effective in livestock production, and their application regimes are often ineffective in dense livestock biotopes (Kim S. et al., 2020). Reports indicate the development of resistance in microbiota to the bactericidal effects of certain disinfectants, making them less effective and economically inefficient (Souza C. et al., 2020; Li Q. et al., 2021).

It is considered that the most environmentally safe disinfection methods are physical ones, including UV radiation, high temperature, and others (Reed N. G., 2010; Memarzadeh F., 2021). However, the implementation of these methods in practical livestock farming is limited due to their high cost, complexity in operation and maintenance, and the lack of a wide range of options on the domestic market. Moreover, there is a significant lack of scientific research dedicated to the effects of physical disinfection methods on the microbiota of livestock premises and the technological schemes for their application on an industrial scale.

Considering the above, it can be concluded that the improvement and scientific-experimental substantiation of disinfection technologies in livestock farming is a relevant task for modern agricultural science.

The aim of our research was to develop innovative devices and methods for disinfecting the air in livestock facilities.

Materials and methods. The development of the devices and methods was carried out based on the results of a patent search and a comparative analysis of existing analogs and prototypes. The work was conducted at the National Scientific Center "Institute of Experimental and Clinical Veterinary Medicine." The effectiveness of disinfectants was evaluated in accordance with current regulatory documents (Kovalenko V. L. et al., 2014).

Results. Most devices designed to maintain the necessary microclimate parameters in livestock facilities are quite bulky, complex to use, unreliable in operation, as well as energy-consuming and metal-intensive.

The first utility model focuses on the development of a device for air purification in livestock facilities. It includes two-stage biological-droplet type filters that are washed with water, sedimentation tanks, water supply control valves, a water recirculation pipeline system, and a water supply and drainage pipeline system. This design allows for effective air purification, provides functional flexibility, ensures optimal investment efficiency, reduces operational costs, significantly lowers energy consumption during use, and minimizes the need for manual cleaning and maintenance (Fig. 1).

The air purification device for livestock facilities consists of two-stage biological-droplet type filters (1) washed with water, sedimentation tanks (2), water supply control valves (3), a water recirculation pipeline system (4), and a water supply and drainage pipeline system (5). The device operates as follows: water is supplied to the device through the water supply and drainage pipeline system (5) and accumulates in the sedimentation tanks (2). Once sufficient water is accumulated, it circulates through the recirculation pipeline system (4).

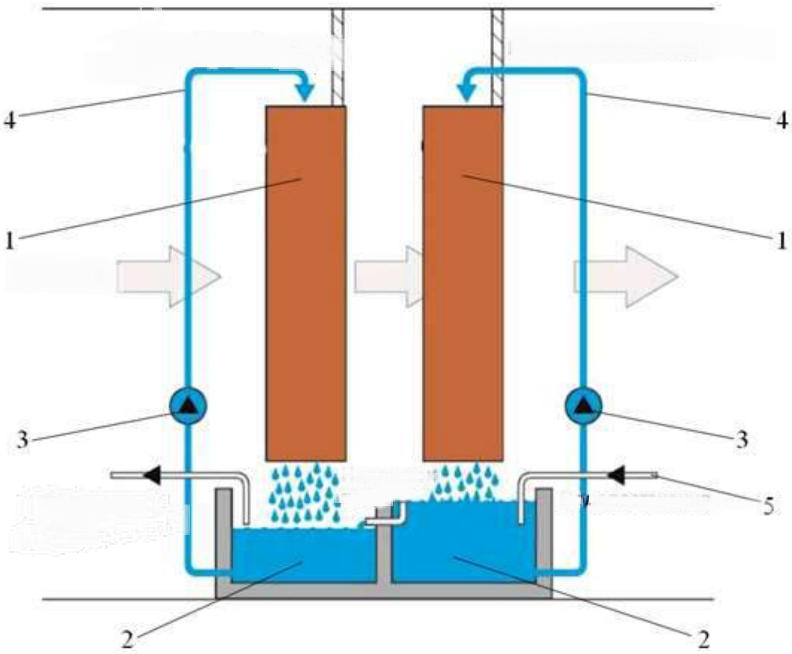

Fig. 1. **Device for air purification in livestock facilities**

Air from the livestock facility is drawn through the two-stage biological-droplet type filters (1), which are washed with water. This process removes ammonia, dust, and odors from the air. A biofilm consisting of various microorganisms naturally present in the air forms on the filters (1). Some microorganisms convert ammonia, while others feed on substances like sludge and dust. The water, after washing the filters (1), flows into the sedimentation tanks (2) and is then recirculated through the pipeline system (4). This water continues to circulate through the filters (1) as long as they can absorb ammonia. Once the water is saturated, it is drained into the sludge collector via the water supply control valves (3) and the drainage system (5), and fresh water is supplied to the system. This development is protected by the Ukrainian utility model patent No. 145194.

The next utility model aims to improve the efficiency of air purification in livestock facilities and reduce energy consumption during the device's operation. This goal is achieved by equipping the device with a source of ultraviolet radiation and a wastewater drainage and treatment system. These enhancements significantly increase the efficiency of air purification while substantially lowering energy consumption during use (Fig. 2).

The air sanitation and ionization device for livestock facilities consists of an air duct (1) containing corona electrodes (2) and a fan (3), a water pipeline (4) installed on the air duct with longitudinal mobility and ending in a shower nozzle (5), a high-voltage power supply unit (not shown), an ultraviolet radiation source (6), a water collection tray (7), a flexible hose (8) with a tap (9) for draining water into a sedimentation tank (10), and a water pump (11). The device operates as follows: water from the pipeline (4) flows into the shower nozzle (5), creating an artificial waterfall.

Air is drawn into the air duct (1) by the operating fan (3), where it is irradiated with ultraviolet rays from the source (6) at the inlet, effectively destroying microorganisms. Simultaneously, the corona electrodes (2) impart a negative charge to the air particles, some of which settle on the water droplets from the artificial waterfall. Coulomb forces arise between the negatively charged particles and the water, causing suspended air particles to settle on the water, thereby compensating for the lack of aeroions in the facility. The water, in turn, flows into the collection tray (7) and is drained via the flexible hose (8) with the tap (9) into the sedimentation tank (10), where mechanical impurities settle to the bottom. The cleaned water is then pumped by the water pump (11) back to the shower nozzle (5), forming a closed-loop system. This innovation is protected by Ukrainian utility model patent No. 71809.

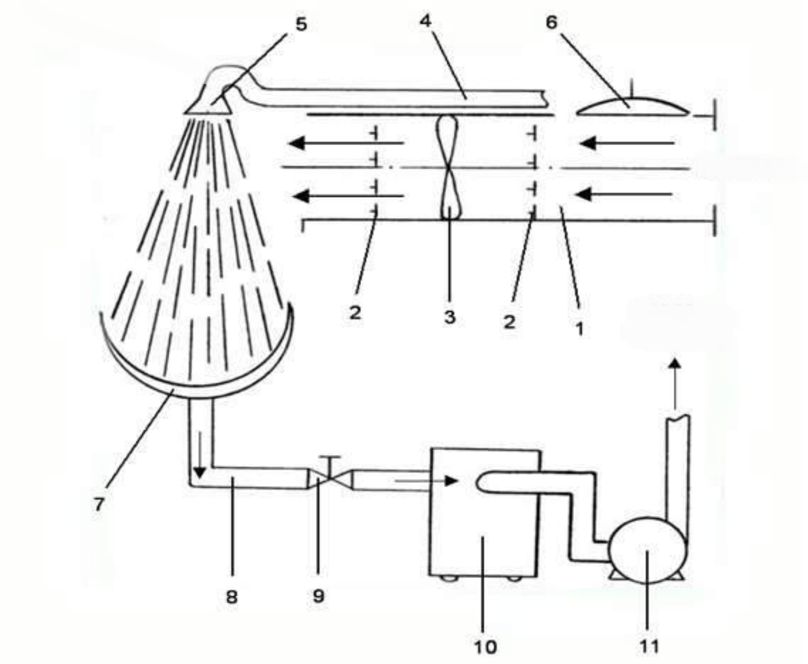

Fig. 2. **Device for air sanitation of livestock facilities**

The next stage of our research involved assessing the effectiveness of chemical disinfectants for air sanitation in livestock facilities. For this purpose, two complex disinfectants were used during aerosol disinfection and fumigation.

In the first case, the task was to develop a method of aerosol disinfection that includes mechanical cleaning of livestock facilities, their sealing, maintaining the appropriate microclimate (temperature not lower than 12 °C, relative humidity not less than 60%), disinfection with a preparation, and bacteriological quality control of the performed disinfection. The disinfectant used contains glutaraldehyde, glyoxal, formaldehyde, quaternary ammonium compounds (QACs), triamine, fog-forming components, and water, with an exposure time of 1 hour.

Thus, before disinfection, the facility is mechanically cleaned of manure, feed residues, debris, etc. Equipment is cleaned of technical and organic contaminants. Floors, ceilings, and walls are washed with water under pressure. Doors, windows, manure channel outlets, and natural and forced ventilation hatches are sealed. The facility’s temperature is maintained at no lower than 12 °C, and the relative humidity at no less than 60%. Aerosol disinfection is then carried out using the following formulations:

Method 1: Glutaraldehyde – 0.78%, glyoxal – 0.24%, formaldehyde – 0.66%, QACs – 0.36%, triamine – 0.09%, fog-forming components – 0.60%, water – 97.27%.

Method 2: Glutaraldehyde – 1.04%, glyoxal – 0.32%, formaldehyde – 0.88%, QACs – 0.48%, triamine – 0.12%, fog-forming components – 0.80%, water – 96.36%.

Method 3: Glutaraldehyde – 1.30%, glyoxal – 0.40%, formaldehyde – 1.10%, QACs – 0.60%, triamine – 0.15%, fog-forming components – 1.0%, water – 95.45%.

Method 4: Glutaraldehyde – 1.56%, glyoxal – 0.48%, formaldehyde – 1.32%, QACs – 0.72%, triamine – 0.18%, fog-forming components – 1.20%, water – 94.54%.

The exposure time was 1 hour.

After disinfection, samples are collected using sterile cotton-gauze swabs soaked in sterile distilled water. Swabs are taken from 10 different areas of the facility, each measuring 10×10 cm, using a metal stencil to define the sampling area. Samples are washed in the same test tube by repeated immersion and squeezing of the swab. The swabs are then removed, and the liquid is centrifuged for 20–30 minutes at 1500 rpm. The supernatant is decanted, and sterile distilled water is added to the sediment, which is shaken and centrifuged again. After the second centrifugation, the supernatant is decanted, and 0.5 cm³ of the centrifugate is inoculated onto nutrient media: meat-peptone broth (MPB) and meat-peptone agar (MPA). The cultures are incubated in a thermostat for 24 hours at 37.0±0.5 °C. Growth is monitored after 12 and 24 hours. The grown culture is examined under a microscope. The disinfection quality is deemed satisfactory if no microbial colony growth is observed in all tested samples.

The efficiency of the proposed method is presented in Table 1.

Table 1

Aerosol disinfection method

<table>
<tr><th rowspan="2">Preparation’s composition</th><th rowspan="2">Concentration, %</th><th colspan="2">Microbial growth</th></tr>
<tr><th>Prior to desinfection</th><th>After desinfection</th></tr>
<tr><td>glutaraldehyde</td><td>0.78</td><td rowspan="7">+</td><td rowspan="7">+</td></tr>
<tr><td>glyoxal aldehyde</td><td>0.24</td></tr>
<tr><td>formaldehyde</td><td>0.66</td></tr>
<tr><td>QAC</td><td>0.36</td></tr>
<tr><td>triamine</td><td>0.09</td></tr>
<tr><td>fog-forming components</td><td>0.60</td></tr>
<tr><td>water</td><td>97.27</td></tr>
<tr><td>glutaraldehyde</td><td>1.04</td><td rowspan="7">+</td><td rowspan="7">+</td></tr>
<tr><td>glyoxal aldehyde</td><td>0.32</td></tr>
<tr><td>formaldehyde</td><td>0.88</td></tr>
<tr><td>QAC</td><td>0.48</td></tr>
<tr><td>triamine</td><td>0.12</td></tr>
<tr><td>fog-forming components</td><td>0.80</td></tr>
<tr><td>water</td><td>96.36</td></tr>
<tr><td>glutaraldehyde</td><td>1.30</td><td rowspan="7">+</td><td rowspan="7">–</td></tr>
<tr><td>glyoxal aldehyde</td><td>0.40</td></tr>
<tr><td>formaldehyde</td><td>1.10</td></tr>
<tr><td>QAC</td><td>0.60</td></tr>
<tr><td>triamine</td><td>0.15</td></tr>
<tr><td>fog-forming components</td><td>1.0</td></tr>
<tr><td>water</td><td>95.45</td></tr>
<tr><td>glutaraldehyde</td><td>1.56</td><td rowspan="7">+</td><td rowspan="7">–</td></tr>
<tr><td>glyoxal aldehyde</td><td>0.48</td></tr>
<tr><td>formaldehyde</td><td>1.32</td></tr>
<tr><td>QAC</td><td>0.72</td></tr>
<tr><td>triamine</td><td>0.18</td></tr>
<tr><td>fog-forming components</td><td>1.20</td></tr>
<tr><td>water</td><td>94.54</td></tr>
</table>

Note: «+» - micribial growth; «–» - no growth.

From the data in Table 1, it is evident that swabs taken from livestock facilities before disinfection revealed the presence of catalase-positive and oxidase-negative staphylococci, *Escherichia coli*, mono- and diplococci. When using a preparation containing glutaraldehyde (0.78–1.04%), glyoxal (0.24–0.32%), formaldehyde (0.66–0.88%), quaternary ammonium compounds (QACs, 0.36–0.48%), triamine (0.09–0.12%), fog-forming components (0.60–0.80%), and water (97.27–96.36%), complete elimination of microorganisms was not achieved, as evidenced by their growth on nutrient media.

In contrast, swabs taken after the application of a preparation containing glutaraldehyde (1.30–1.56%), glyoxal (0.40–0.48%), formaldehyde (1.10–1.32%), QACs (0.60–0.72%), triamine (0.15–0.18%), fog-forming components (1.0–1.2%), and water (95.45–94.54%) showed no microbial growth in any case.

The results of the conducted studies indicate that the proposed aerosol disinfection method meets modern requirements for livestock facility management. It is effective, environmentally safe, economical, and easy to apply. This development is protected by the Ukrainian patent for a utility model № 96618.

The second utility model aimed to develop a fumigation disinfection method, which includes the mechanical cleaning of livestock premises, their sealing, maintaining the appropriate microclimate (temperature 12–35 °C), and disinfection using a preparation containing peracetic acid, acetic acid, hydrogen peroxide, and water, with an exposure time of 30 minutes and a consumption rate of at least 20 ml/m³.

Prior to disinfection, the premises are mechanically cleaned of manure, feed residues, debris, etc. Equipment is cleaned of technical and organic contaminants. The floor, ceiling, and walls are washed with pressurized water. Doors, windows, manure channel openings, and natural and forced ventilation hatches are tightly sealed. The temperature inside the premises is maintained at 12–35 °C. Disinfection is then carried out by fumigation with the following formulations:

Method 1: peracetic acid – 0.75 %; acetic acid – 0.95 %; hydrogen peroxide – 1.05 %; water – 97.25 %.

Method 2: peracetic acid – 1.20 %; acetic acid – 1.52 %; hydrogen peroxide – 1.68 %; water – 95.60 %.

Method 3: peracetic acid – 1.50 %; acetic acid – 1.90 %; hydrogen peroxide – 2.10 %; water – 94.50 %.

Method 4: peracetic acid – 1.80 %; acetic acid – 2.28 %; hydrogen peroxide – 2.52 %; water – 93.40 %.

The efficiency of the proposed method is presented in Table 2.

The data from Table 2 show that using a preparation containing peracetic acid (0.75–1.20%), acetic acid (0.95–1.52%), hydrogen peroxide (1.05–1.68%), and water (97.25–95.60%) does not fully disinfect the treated veterinary surveillance objects.

In contrast, swabs taken after applying a preparation with higher concentrations of peracetic acid (1.50–1.80%), acetic acid (1.90–2.28%), hydrogen peroxide (2.10–2.52%), and water (94.50–93.40%) showed no microbial growth in any case, indicating complete disinfection of the treated objects.

The results of the conducted studies demonstrate that the proposed fumigation disinfection method meets modern livestock management requirements. It is effective, environmentally safe, technological, economical, and simple to use. This development is protected by the Ukrainian patent for utility model No. 104050.

Table 2

Fumigation disinfection method

Preparation's composition	Concentration, %	Microbial growth	
		Prior to desinfection	After desinfection
peracetic acid	0.75	+	+
acetic acid	0.95		
hydrogen peroxide	1.05		
water	97.25		
peracetic acid	1.20	+	+
acetic acid	1.52		
hydrogen peroxide	1.68		
water	95.60		
peracetic acid	1.50	+	–
acetic acid	1.90		
hydrogen peroxide	2.10		
water	94.50		
peracetic acid	1.80	+	–
acetic acid	2.28		
hydrogen peroxide	2.52		
water	93.40		

Note: «+» - micribial growth; «–» - no growth.

The foundation of this utility model aims to develop a method for deodorizing livestock facilities, which includes mechanical cleaning of livestock premises and deodorizing them using a preparation that serves as a disinfectant. The preparation contains benzalkonium chloride, eucalyptus oil, fir oil, thyme oil, and water, with an exposure time of 15 minutes at a dosage of 1–2 cm^3 per 1 m^3 of the room's volume.

Before deodorization, mechanical cleaning of the premises is carried out to remove manure, feed residues, debris, and other waste. Following this, the deodorization of the premises is performed using the preparation with the following compositions:

Method 1: benzalkonium chloride 0.008%, eucalyptus oil 0.0018%, fir oil 0.0018%, thyme oil 0.0018%, water 99.9866%.

Method 2: benzalkonium chloride 0.024%, eucalyptus oil 0.0054%, fir oil 0.0054%, thyme oil 0.0054%, water 99.9598%.

Method 3: Benzalkonium chloride 0.04%, eucalyptus oil 0.009%, fir oil 0.009%, thyme oil 0.009%, water 99.933%.

Method 4: Benzalkonium chloride 0.056%, eucalyptus oil 0.0126%, fir oil 0.0126%, thyme oil 0.0126%, water 99.9062%.

The results of the method's effectiveness are presented in Table 3.

The data in Table 3 show that when using the preparation containing benzalkonium chloride at 0.008–0.024%, eucalyptus oil at 0.0018–0.0054%, fir oil at 0.0018–0.0054%, thyme oil at 0.0018–0.0054%, and water at 99.9866–99.9598%, the unpleasant odor in the premises was not completely eliminated.

However, it was found that when using the preparation containing benzalkonium chloride at 0.04–0.056%, eucalyptus oil at 0.009–0.0126%, fir oil at 0.009–0.0126%, thyme oil at 0.009–0.0126%, and water at 99.933–99.9062% with an exposure time of 15 minutes at a dosage of 1–2 cm^3 per 1 m^3 of room volume, unpleasant odors were absent for 24 hours.

Table 3

Deodorizing method in livestock farming

Preparation's composition	Concentration, %	Unpleasant odor	
		Prior to deodorizing	after deodorizing
benzalkonium chloride	0.008 %	+	+
eucalyptus oil	0.0018 %		
fir oil	0.0018 %		
thyme oil	0.0018 %		
water	99.9866 %		
benzalkonium chloride	0.024 %	+	+
eucalyptus oil	0.0054 %		
fir oil	0.0054 %		
thyme oil	0.0054 %		
water	99.9598 %		
benzalkonium chloride	0.04 %	+	–
eucalyptus oil	0.009 %		
fir oil	0.009 %		
thyme oil	0.009 %		
water	99.933 %		
benzalkonium chloride	0.056 %	+	–
eucalyptus oil	0.0126 %		
fir oil	0.0126 %		
thyme oil	0.0126 %		
water	99.9062 %		

Note: «+» - presence of unpleasant odor; «–» - odor is absent.

The results of the conducted studies indicate that the proposed method of deodorization in livestock facilities meets modern production organization requirements, is effective, environmentally safe, economical, and simple. This development is protected by Ukrainian Utility Model Patent No. 95338.

Discussion. The role of air pollution in the development of respiratory diseases, including acute respiratory infections and chronic obstructive pulmonary diseases, is well-documented. Therefore, the use of air purifiers and filters is one of the proposed strategies to improve indoor air quality (Vijayan V. K. et al., 2015). Filtration of recirculated air results in the lowest overall dust concentration (0.12 mg/m^3), and lung health is found to be the best in animals housed in facilities equipped with recirculated air filtration modules (Wenke C. et al., 2018). To address issues associated with high dust concentrations, ventilation systems with air filters and humidity control have been introduced. However, their widespread adoption is hindered by high costs, significant energy consumption, and labor-intensive maintenance (Hou R. et al., 2024). Our proposed technical solutions offer high efficiency and functional flexibility, ensuring optimal capital investment efficiency and reduced operational costs.

The effectiveness of disinfection technologies based on ultraviolet (UV) radiation is promising, but it depends on numerous environmental, physical, and technical factors. UV disinfection should not be used in isolation but should be considered as a supplement to protocol-driven standard operating procedures for cleaning and disinfection (Memarzadeh F., 2021). Therefore, we consider combining physical and chemical methods for air sanitation in livestock facilities, which, in turn, will minimize the risks of uncontrolled spread of airborne pollutants.

A wide range of antimicrobial agents is used in livestock production; however, not all are environmentally safe and highly effective (Campagna M. V. et al., 2016). In our research, we employed modern chemical disinfectants that demonstrated high efficiency under industrial conditions, allowing us to develop technological protocols for their application. According to other researchers, aldehyde-based aerosol disinfectants have also shown high effectiveness in poultry houses (Jiang L. et al., 2018). The use of peracetic and acetic acids in spray methods for intermediate disinfection is recommended (Scheib S. et al., 2023).

Odor emissions significantly affect human and animal health as well as the environment (Cao T. et al., 2023). For deodorizing livestock facilities, we propose using eucalyptus, fir, and thyme oils in appropriate concentrations, which have proven effective in combating unpleasant odors. Other scientists suggest using deodorizing microbial strains (Ma H. et al., 2021). The spraying of plant extracts is also recommended by other researchers (Wang Y. C. et al., 2021).

It has been reported that washing followed by disinfection is not always highly effective. Therefore, the use of technological breaks by relocating animals in facilities is proposed as an alternative (Connor J. T. O. et al., 2017).

Thus, despite the progress achieved in the development and implementation of disinfection technologies, there remains a need to explore more environmentally friendly and versatile antimicrobial agents, as well as to develop technical solutions for sanitizing livestock facilities.

Conclusions:

1. The proposed device for air purification in livestock facilities is economical, simple, and convenient to use. It ensures complete air environment purification, is reliable in operation, requires minimal manual cleaning and maintenance, and offers functional flexibility, which guarantees optimal investment efficiency and reduced operational costs.
2. The proposed device for air sanitation in livestock facilities enables simultaneous air ionization and ultraviolet radiation treatment to eliminate pathogenic and opportunistic microorganisms. It is reliable, simple to use, economical, and does not require significant material or energy expenditures.
3. Developed methods for deodorization, aerosol disinfection, and fumigation of the air environment in livestock facilities involve the use of innovative disinfecting agents.
4. The prospect of further research lies in improving technological approaches to the disinfection of livestock facilities.

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