Experimental studies on the effect of electric field on ammonium nitrogen compounds in livestock wastewater

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Abstract. The article presents the results of experimental studies on the effects of electric fields on the concentration changes of ammonium forms of nitrogen in aqueous solutions, hereafter referred to as electrolytes, which are wastewater from livestock complexes, considered one of the most dangerous environmental pollutants. The aim of the laboratory experimental research was to study the impact of electric fields on the concentration changes of ammonium nitrogen compounds in aqueous solutions (electrolytes), for the further development of technical means to reduce their concentration and improve the environmental safety of wastewater disposal from livestock complexes on agricultural crop fields. Existing wastewater treatment methods are divided into two groups: the first is a regenerative group, which involves extracting mineral substances from wastewater and reusing them. The results of the experimental studies are aimed at improving the effectiveness of the destructive group to ensure environmental safety and enhance the quality of crop production when using livestock effluents on agricultural fields.

1 Introduction

The transition to bedding-free animal husbandry systems utilizing hydraulic flushing has resulted in a significant increase in livestock effluents, exacerbating environmental protection concerns, particularly due to the high concentrations of mineral substances present in these effluents [1,2]. This issue is especially acute in Russia, where the agricultural sector plays a substantial role in the national economy and numerous livestock complexes exist. Large farms generate between 100 and 1500 cubic meters of liquid waste requiring disposal daily [3].

Nitrogen is a crucial component in plants, forming part of proteins, nucleic acids (RNA, DNA), chlorophyll, and enzymes, all of which play vital roles in metabolism. It is also present in the form of nitrogen compounds such as nitrates, nitrites, and ammonia. While plants can accumulate excess nitrogen without harm, excessive levels pose health risks to humans and animals. High nitrogen doses can deteriorate crop quality, disrupt sugar-protein and calcium-phosphorus ratios, and significantly increase nitrate content.

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Mineral nitrogen in soil primarily exists as ammonium, nitrates, and nitrites. Nitrites, present in small quantities, are not absorbed by the soil-adsorption complex. Soil ammonium partially undergoes nitrification through microbial oxidation processes [4,5].

Currently, the most environmentally safe and economically viable method for managing livestock effluents is their application to agricultural fields. This approach allows a significant portion of the substances in the effluents to be removed with the harvest. However, it necessitates careful monitoring of crop quality, particularly nitrogen content in the produced crops [6-9].

The objective of the laboratory experimental studies was to investigate the effects of electric fields on the concentration changes of ammonium nitrogen compounds in aqueous solutions (electrolytes). This research aims to develop technical means for reducing their concentration and enhancing the environmental safety of wastewater disposal from livestock complexes on agricultural fields.

2 Materials and methods

The wastewater from livestock complexes contains, on average, 0.8 to 1.4 kg of nitrogen, 0.3 to 0.7 kg of phosphorus, and 0.4 to 1.2 kg of potassium per cubic meter. The mineral portion of nitrogen in these effluents is primarily present in the form of ammonium, which is found in higher concentrations than phosphorus and potassium mineral compounds, making it a significant source of nitrogen compounds entering the soil. Overall, the wastewater contains 3.2% total nitrogen by volume, with more than 50% of this nitrogen existing in easily soluble ammonium form. The composition of wastewater from livestock complexes is summarized in Table 1 [10].

Table 1. Composition of wastewater from livestock complexes.

No	Wastewater	pH	K	NH_4	P_2O_5	Suspended sediment
Concentration mg/l						
1	Wastewater from pig farms	7.5	274	573	152	1347
2	Wastewater from cattle	7.4	860	420	158	1347

The following equipment was used for conducting the research, as shown in Figure 1:

- electrode columns made of aluminum tubes (alloy AD31T1) with external diameters of 16 mm and 50 mm. The external electrical insulation was implemented using two layers of heat-shrink sleeves, model F70, with a maximum load capacity of 10 kV for each layer;
- a tester for direct and alternating current up to 600 V;
  a pH meter with a measurement range of 0-14 and an accuracy of 0.01;
- a digital caliper with a measurement accuracy of 0.1 mm;
- professional NH3/NH4 water tests manufactured by NILPA and UHE companies;
- a TDS meter (model IK-1) produced by TEKHMETR company for determining the total salt content in the electrolyte and its temperature;
- a gas analyzer capable of detecting gaseous forms of nitrogen, manufactured by HABOTEST company;
- a laboratory DC power supply (RGK PS-1326) with maximum values of 6 A for direct current and 32 V for voltage.

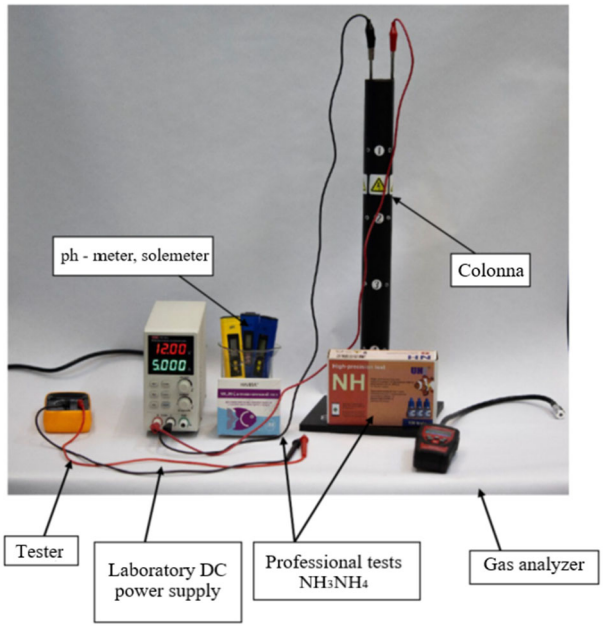

Fig. 1. Materials and equipment used in the experiment.

For the experimental studies, the connection scheme shown in Figures 2 and 3 was employed, where the outer electrode of the column served as the cathode and the inner electrode as the anode, with a direct current of 12 V and 5 A.

The column specifications are as follows:

Inner electrode (+anode) parameters:

- contact surface diameter (d_{inside}) = 0.016 m;
- circle length (l_{inside}) = 0.05 m;
- contact surface area at electrolyte level in the static experimental setup (U = 0.295 m): S_{inside} = 0.015 m²
- cross-sectional area: d_{inside} = 0.0001 m².

Outer electrode (-cathode) parameters:

- contact surface diameter ($d_{outside}$) = 0.046 m;
- circle length ($l_{outside}$) = 0.144 m;
- contact surface area at electrolyte level in the static experimental setup (U = 0.295 m): $S_{outside}$ = 0.042 m²;
- cross-sectional area: d_{inside} = 0.0003 m².

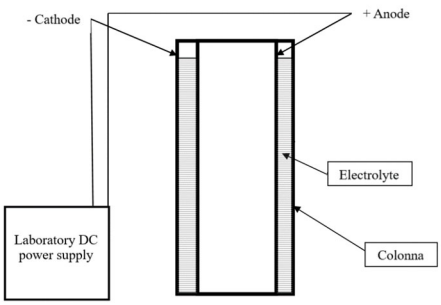

Fig. 2. Schematic diagram of the experimental setup.

Fig. 3. Assembled experimental setup.

To simulate the ammonium content in the electrolyte, distilled water was supplemented with ammonium nitrate, followed by the determination of nitrogen compound concentration (mg/L), pH value, and total dissolved solids (TDS) in parts per million (PPM). A volume of 500 mL of electrolyte was loaded into a column between electrodes (Fig. 2) and treated with direct current. The treatment duration for each experiment was 1, 3, 4, and 9 minutes, respectively, during which the emission of gaseous nitrogen compounds was monitored using a gas analyzer. Upon completion of the experiment, the following electrolyte parameters were measured: nitrogen compound concentration (mg/L), pH value, and total dissolved solids (TDS) in PPM.

3 Results and discussion

Figure 4 illustrates the results of the experiment conducted with an initial NH_3NH_4 concentration of 60 mg/L and corresponding treatment time intervals of 1, 3, 4, and 9 minutes.

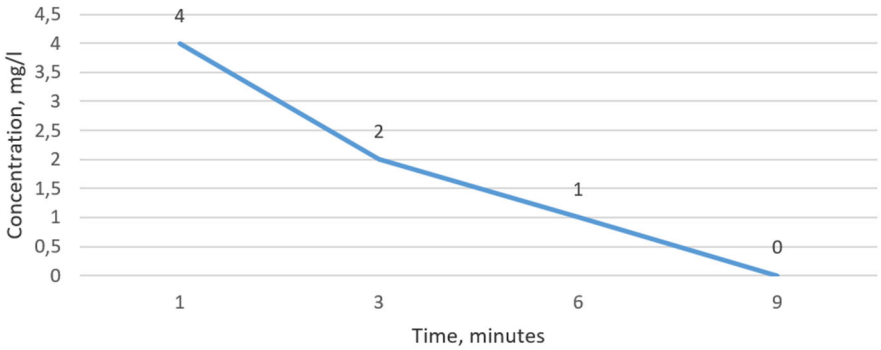

Fig. 4. Change in electrolyte concentration depending on treatment time at an initial value of 60 mg/l NH_3NH_4.

Figure 5 illustrates the results of experimental studies conducted with an initial concentration of nitrogen compounds in the electrolyte at 90 mg/L. The content of NH_3NH_4 relative to the initial concentration, as a function of treatment time, was observed to be 6, 4, 2, and 0 mg/L, respectively.

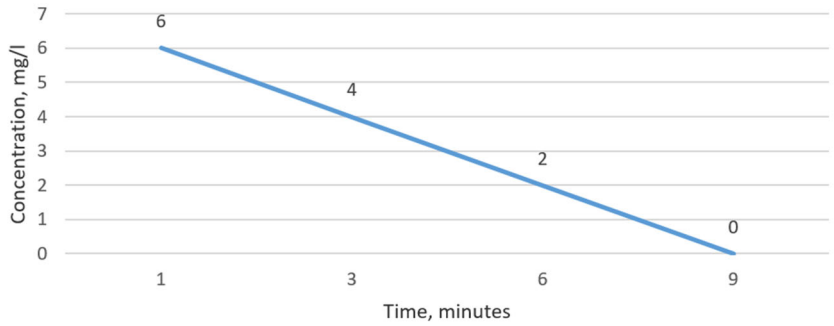

Fig. 5. Change in electrolyte concentration depending on treatment time at an initial value of 90 mg/l NH_3NH_4.

In the subsequent series of experiments, the initial concentration was set at 300 mg/L NH_3NH_4. At the same time intervals as in the previous experiment, the final concentrations were measured at 75, 65, 45, and 15 mg/L, compared to the initial concentration of 300 mg/L.

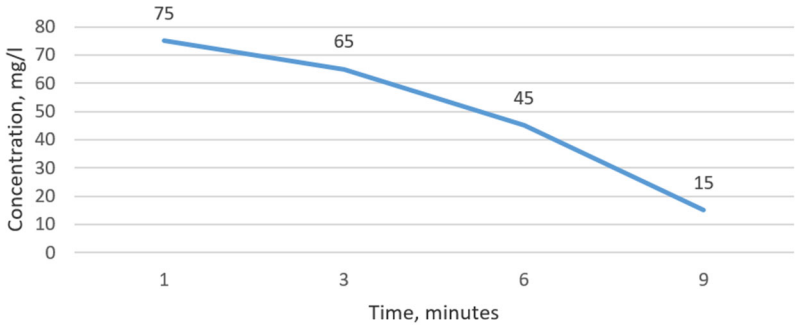

Fig. 6. Change in electrolyte concentration depending on treatment time at an initial value of 300 mg/l NH_3NH_4.

Analysis of the results presented in Figure 4 reveals that the concentration of nitrogen compounds was 4 mg/L after 1 minute, 2 mg/L after 3 minutes, 1 mg/L after 6 minutes, and 0 mg/L after 9 minutes. This indicates a reduction in NH_3NH_4 concentration from 60 mg/L to 0 mg/L over the 9-minute experimental period.

A similar decreasing concentration trend was observed in the experiment (Figure 5) with an initial nitrogen compound concentration of 90 mg/L in the electrolyte.

The pH value changes, as shown in Figure 6, were as follows:

- for an initial ammonium nitrogen concentration of 60 mg/L in the electrolyte, the initial pH was 6.0, with a maximum final pH of 8.4 observed after 9 minutes of treatment.
- for an initial ammonium nitrogen concentration of 90 mg/L in the electrolyte, the initial pH was 5.58, with a maximum final pH of 7.81.

- for an initial concentration of 300 mg/L, the initial pH was 5.53, with a maximum final pH of 8.88.

These results demonstrate a consistent increase in pH across all experimental conditions, correlating with the reduction in ammonium nitrogen concentration.

4 Conclusion

The conducted laboratory experimental studies demonstrated the potential for reducing the concentration of ammonium compounds in aqueous solutions (electrolytes), which represent wastewater from livestock complexes.

At a concentration of 300 mg/L, approximating the actual levels found in livestock complex wastewater, and with a minimum treatment time of 1 minute, the final concentration achieved was 75 mg/L. This result indicates the promise of this purification method and supports the development of an industrial prototype for livestock wastewater treatment.

The reduction in ammonium nitrogen concentration diminishes the environmental burden, particularly on soil, groundwater, and surface water. The development and application of a technical device based on the principle of electric field exposure could enhance the quality of crop production cultivated on agricultural lands where livestock wastewater is utilized.

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