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Improved techniques for the reduction of microbial contamination toxic gas content in the air of the poultry houses

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The issue of protecting the environment from harmful emissions is currently urgent for virtually all poultry farms. At the same time, the increased concentrations of ammonia, carbon dioxide and hydrogen sulfide in the air of the poultry houses have a negative impact on the physiological state of the bird's organism and farm personnel. The purpose of the research was to determine the effectiveness of the use of advanced techniques to reduce the microbial contamination of the air in the poultry houses and the content of toxic gases in the real production conditions and the economic effect of their use. We registered that ammonia content in the air of poultry houses of the new variant decreased by 2.6 times on the first day and by 1.9 times on the fifth day compared to the basic variant during the cold season; during the transition season it decreased by 2.3 times and 1.7 times, respectively. The total weight of the litter after removal from the premises in the experimental poultry house was by 95 t less than in the basic version, which allowed reducing transport costs. In the new version, 104,050 eggs or 18.834 t of egg mass more were received. The use of the proposed technological solutions contributed to some reduction in the specific feed cost: by 329 g - per 1 average laying hen, 11 g per 10 eggs, 51 g or 2.3% - per 1 kg of egg mass. The application of the proposed technological solutions provides an annual economic effect of 769.2 UAH per 1,000 heads and a payback period of additional costs is 0.7 years.

Keywords: Poultry house; Toxic gases; Air; Bacterial contamination; Microclimate

Introduction

Air pollution is one of the important environmental problems of nowadays. Therefore, the intensification and concentration of modern poultry farming have provoked new problems not only to the technological industry. Effective methods of treatment and disposal of poultry waste for environmental protection are becoming increasingly important (Dunlop et al., 2016; Palii & Ishchenko, 2019). The dynamic development of intensive industrial poultry farming has made this livestock sector a powerful source of harmful gases. Ventilation systems emit significant amounts of carbon dioxide, ammonia, nitrogen oxides, sulfur, hydrogen sulfide and dust from the poultry houses. It is an important environmental factor of anthropogenic and technogenic origin, which is dangerous not only for the microclimate of poultry, the health of poultry workers, the sanitary regime, but also for the ecological status of the air pool around the poultry farm (Marchenko, 2010).

Taking into consideration the existing problem, it is necessary to develop measures to reduce the level of air pollution in the area of exposure of poultry farms. In general, measures for the protection of the air basin of poultry farms can be divided into general and individual ones. General measures to combat air pollution include a high sanitary culture of the industry, uninterrupted operation of microclimate systems (primarily ventilation), removal of litter, thorough cleaning and disinfection of premises, the organization of sanitary protection zone, etc. (Chidambaranathan & Balasubramanium, 2017; Linlin et al., 2018; Saeed et al., 2018).

In addition, individual (technological, sanitary) measures are needed to clean, disinfect and deodorize the air and contribute to reducing the flow of pollutants into the environment (Calvet et al., 2010; Tihonchuk, 2015).

The poultry differs from other animal species by more intensive metabolism. Thus, 5-6 times as much carbon dioxide and warmth is released and oxygen absorbed per 1 kg of chicken mass as per 1 kg of cattle. In addition, during the decomposition of litter a large amount of harmful gases is accumulated in the air, as poultry litter contains 20-25% of various underutilized substances, including proteins containing sulfur. Under the influence of microflora, heat and moisture, litter decomposes, resulting in the formation of ammonia and hydrogen sulfide (Broucek & Cermak, 2015; Tan et al., 2019).

Increasing the concentration of carbon dioxide in the air of the premises has a negative effect on the physiological state of the body. It inhibits the oxidation processes, increases the acidity of the tissues, decreases the alkaline reserve of blood and demineralization of bone tissue occurs. In addition, inhaling air with high CO_2 content causes disturbances in body temperature regulation. In mammals, increasing the amount of carbon dioxide in the blood causes excitation of the respiratory center, resulting in impaired breathing. In a bird, by contrast, an increase in the concentration of carbon dioxide in the blood contributes to slowing down breathing and can even cause it to stop completely, and during a prolonged stay in a premise where the carbon dioxide content in the air exceeds 0.3%, chronic bird poisoning may occur: it becomes sluggish, its development slows down and sometimes absolutely stops (McKeegan et al., 2011).

Ammonia is a toxic gas, which also has a negative impact on the health and productivity of animals. Prolonged inhalation of the air with the content of even a small amount of ammonia weakens the resistance of the body and promotes various diseases, especially pulmonary ones. This occurs because a favorable environment for the activation of conditionally pathogenic microflora is created in the respiratory mucosa. Prolonged inhalation of air with high concentrations of ammonia decreases the content of hemoglobin and erythrocytes in the blood, anemia occurs. In addition, the function of the digestive tract, digestion of protein substances, fat and fiber, which leads to a general weakening of the body. The poultry suffers from lacrimation, conjunctivitis and inflammation of the trachea, bronchi, lungs, reduced feed intake and nutrient absorption. At the same time, puberty is delayed, local and general resistance of the body to the effect of harmful factors is weakened, the bird becomes more susceptible to infectious diseases (Al-Homidan et al., 2003; Naseem & King, 2018).

Hydrogen sulfide is also very toxic. Its high content in the air contributes to the inhibition of oxidation processes in the body, can cause inflammation and swelling of the lungs, which is one of the reasons for the oxygen starvation of the bird. Hydrogen sulfide has a negative effect on the nervous system. Prolonged inhalation of elevated hydrogen sulfide concentrations may result in chronic poisoning (Saksrithai, 2018).

Thus, increasing concentrations of ammonia, carbon dioxide, and hydrogen sulfide in the air of the poultry house have a negative effect on the overall physiological state of the bird's organism (Burns et al., 2007; Calvet et al., 2011). Productivity and natural resistance of the bird depend on both heredity and full feeding, and on conditions of keeping, microclimate, and the gas composition is the main parameter of it. Therefore, poultry houses must be equipped with effective ventilation systems (Casey et al., 2008).

The nature of the epizootic process in conditions of intensive poultry farming is characterized by the fact that even weakly virulent and opportunistic microflora as a result of recirculation and frequent passages is able to increase virulent properties and create serious epizootic and epidemiological threat (Mendes et al., 2014; Paliy et al., 2018b). Another, not less important feature is that the pathogenic microflora is able to maintain viability for a long time, especially in organic waste from poultry farms (Oakley et al., 2013). For example, pathogens of salmonellosis and colibacteriosis remain viable for 12 months, and tuberculosis agents - for 18 months (Dumas et al., 2011; Milanov et al., 2017).

The issue of protecting the environment from pollution by bird litter, sewage and non-food waste from poultry processing is currently urgent for virtually all poultry farms in Ukraine (Tertichnaya et al., 2017). Recently, a negative trend is emerging, which can lead in the near future to an ecological catastrophe with unpredictable negative consequences not only for residents of settlements, but also for the flora and fauna of poultry farm areas and neighboring territories. The occurrence of infectious and invasive diseases in humans, animals and birds is also quite real (Donham et al., 2002; Paliy et al., 2018c).

The analysis of the development of the industry in recent years shows that today and in the long term prospective the main attention in poultry production should be paid mainly to large poultry farms (Zhao et al., 2015). Nevertheless, this is one important part in the development of industrial poultry. The creation of conditions for reliable protection of the environment from pollution by organic waste and toxic gases coming in large quantities from poultry farms is another equally important component.

Methods

The purpose of the research was to determine the effectiveness of the proposed techniques for reducing the microbial contamination of the air in the poultry houses and the content of toxic gases when keeping laying hens and the economic effect of their use as elements of poultry technology.

According to the previous research (Ishchenko et al., 2019; Palii et al., 2019c; Palii et al., 2020), a modernized air mixer for the drying of litter on the belt conveyors of cage batteries was supplied for production testing. It comprised technological solutions for reducing the content of ammonia and microorganisms in the air of poultry houses such as: a phosphogypsum reagent scrubber, a bactericidal device, and the modes of their use based on the results of the researches.

At one time 150 kg of phosphogypsum were loaded into the scrubber. The reagent was replaced once every 5 days on the day of the removal of the litter. The bactericidal device was installed in the collector air duct of the mixer. The air mixer was insulated by coating it with a layer of foam insulation. The total thickness of the additional insulating material (brick + insulating material) was 35 cm.

The production testing lasted 12 months. During the cold season (December-February) the air exchange in the poultry house was maintained at an average of 0.7 m^3/h, during the transition season (October-November and March-April) - 1.5 m^3/h and during the warm season it was 6 m^3/h per 1 g of live weight of the bird.

The production testing of the proposed developments was carried out in two similar 18×96 m poultry houses of the agricultural company 'AVIAS' equipped with Hellmann 4-tier cage batteries with a litter removal system and built-in ducts. The capacity of each poultry house was 47.280 laying hens.

Materials for the study were laying hens of the high-performance Lohmann Brown hens reared for eggs, avian manure, poultry microclimate, methods and modes of reducing the content of toxic gases in the air of the poultry houses and its contamination with microorganisms, zootechnical and economic poultry indicators. Data were processed by Microsoft Excel software. Methods of zootechnical, zoo-hygienic, biochemical, statistical and economic research were applied when carrying out the research work and processing the research materials.

Results and Discussion

The production testing generally confirmed the results of preliminary tests of the proposed technological solutions (Palii et al., 2019a; Palii et al., 2019b; Palii et al., 2019c; Palii et al., 2020). The ammonia content in the air of the poultry house in the new variant during the cold season reduced by 2.6 times on the first day of application of the reagent, by 2.4 times - on the third day

and by 1.9 times on the fifth day compared to the basic variant. This was caused by the complex effect of the reagent in the scrubber and the ultraviolet radiation in the bactericidal device onto the toxic gases (Table 1).
During the transition period of the year, the ammonia content in the air of the poultry house in the new variant reduced by 2.3 times on the first day, by 1.9 times on the third day and by 1.7 times on the fifth day of application of the reagent compared to the basic variant. The difference in ammonia content between the new and basic variants in the cold and transition seasons was statistically significant. There was no significant difference in carbon dioxide content between the basic and new variants.
Hydrogen sulfide was recorded in the poultry house (basic variant) during the cold season only on the fifth day of accumulation. During the warm season, the scrubber and bactericidal device were not used, so no significant difference in toxic gas content in the poultry house was observed between the basic and new variants during this period of the year.

Table 1. Content of toxic gases in the air of the poultry house (basic and new variants).

Indicators	**Day**		
	First	**Third**	**Fifth**
Basic variant			
content of toxic gases during the cold season:			
ammonia, mg/m^3	10.1 ± 0.54	12.9 ± 0.47	14.8 ± 0.43
carbon dioxide, %	0.09 ± 0.0041	0.11 ± 0.0048	0.12 ± 0.038
hydrogen sulfide, mg/m^3	-	-	1.0 ± 0.26
content of toxic gases during the transition period:			
ammonia, mg/m^3	7.9 ± 0.47	9.1 ± 0.36	11.3 ± 0.46
carbon dioxide, %	0.07 ± 0.0036	0.08 ± 0.0034	0.10 ± 0.042
content of toxic gases during the warm season:			
ammonia, mg/m^3	5.2 ± 0.41	7.3 ± 0.35	9.4 ± 0.39
carbon dioxide, %	0.06 ± 0.0037	0.07 ± 0.0042	0.09 ± 0.0047
new variant			
content of toxic gases during the cold season:			
ammonia, mg/m^3	3.9 ± 0.43*	5.4 ± 0.48*	7.9 ± 0.45*
carbon dioxide, %	0.08 ± 0.0032	0.12 ± 0.0026	0.11 ± 0.0041
content of toxic gases during the transition period:			
ammonia, mg/m^3	3.4 ± 0.52***	4.7 ± 0.48***	6.8 ± 0.56***
carbon dioxide, %	0.08 ± 0.0031	0.08 ± 0.0043	0.09 ± 0.0039
content of toxic gases during the warm season:			
ammonia, mg/m^3	5.1 ± 0.54	7.5 ± 0.53	9.2 ± 0.47
carbon dioxide, %	0.07 ± 0.0034	0.07 ± 0.0047	0.08 ± 0.0036

Here and then: * P≤0.05, ** P≤0.01, *** P≤0.001.

During the production inspection, humidity and chemical composition of the litter on the 5th day of accumulation on the belt conveyors of cage batteries were determined (Table 2).

Table 2. Chemical composition of the litter in the poultry houses.

Season	**Humidity, %**	**Content in absolutely dry weight of the matter, %**		
		Nitrogen	**Phosphorus**	**Potassium**
Basic variant (control poultry house)				
Cold	55.9 ± 0.87	4.52 ± 0.028	2.83 ± 0.043	1.79 ± 0.021
Transition	49.5 ± 1.06	4.66 ± 0.032	2.77 ± 0.038	1.81 ± 0.023
Warm	38.3 ± 0.93	4.72 ± 0.027	2.89 ± 0.047	1.8 ± 0.019
New variant (experimental poultry house)				
Cold	48.8 ± 0.84**	4.69 ± 0.026**	2.81 ± 0.038	1.82 ± 0.021
Transition	44.9 ± 1.09*	4.74 ± 0.037	2.85 ± 0.047	1.78 ± 0.024
Warm	38.4 ± 0.85	4.70 ± 0.025	2.79 ± 0.034	1.76 ± 0.017

As with the previous studies, the upgraded air mixer provided a significant intensification of the process of drying the litter during the cold and transition seasons: by 7.1% (P≤0.01) and 4.6% (P≤0.05), respectively. During these periods of the year, there was also a tendency to the reduction of nitrogen losses from the litter in the experimental poultry house, with the difference between the experimental and control poultry house being statistically significant during the cold season. There was no significant difference in phosphorus and potassium content between the new and basic variants (Table 3).

During the periods of the year, when the poultry was kept in the new poultry house, a decrease for litter received was recorded by 1.2 times during the cold season; 1.1 times in the transition period and 1.0 times - in the warm season compared to the basic variant. In the experimental poultry house, the total weight of the litter after removal from the poultry house was 95 t less than in the basic variant, which allowed reducing transport costs. In addition, a decrease in the yield of dried litter per day, by 5.5 g (1.1 times), compared to the basic poultry house was recorded in the new poultry house.

The main zoo technical indicators for keeping the poultry in the basic and new variants are shown in Table 4.

Table 3. The quantitative characteristics of litter obtained.

Indicators	Basic variant	New variant
Amount of fresh litter obtained per year, t	2452 (W[xx]=69.8%)	2469 (W=69.8%)
Total amount of dried litter per year (t), including:		
during the cold season	1413	1318(-95[x])
during the transition season	423 (W=55.9%)	363 (W=48.8%)
during the warm season	490 (W=49.5%)	452 (W=44.9%)
	500 (W=38.3%)	503 (W=38.4%)
Mass of dried litter compared to fresh litter, %	57.6	53.6
Output of the dried litter from laying hen per day, g	81.9	76.4(-5.5[x])

[x] - less by the specified value compared to the basic variant; [xx] - humidity of the litter.

Table 4. The main zootechnical indicators for keeping laying hens.

Indicators	Basic variant	New variant
Initial number of birds in the poultry house, heads	47280	47280
Poultry stock at the end of the experiment, heads	44727	45436
Duration of the experiment, days	365	365
Mass of the poultry, g/head:		
at the beginning of production testing	1387.5 ± 34.2	1388.6 ± 29.3
at the end of production testing	1997.7 ± 43.6	1983.3 ± 31.6
Poultry survival rate, %	94.6	96.1***
Amount of eggs per laying hen, t	290.3	292.5*
Average weight of the egg, g	61.4 ± 0.17	62.3 ± 0.19**
Egg mass per laying hen, kg	17.824	18.223(+0.399)
Total amount of eggs in the poultry house:		
thousands	13725.38	13829.40(+104.05)
tones	842.738	861.572(+18.834)
Feed expenditures:		
average laying hen per day, g	113.0	112.1
per 10 eggs, kg	1.382	1.371(-0.011)
per kg of egg mass, kg	2.251	2.200(-0.051)
totally during a year in the poultry house, t	1897.4	1895.8

In the experimental poultry house, 1.5% higher poultry survival (P≤0.001) was marked; and more than 2.2 (P≤0.05) eggs per initial laying hen were obtained. A mass of eggs in the experimental poultry house was also 0.9 g greater (P≤0.01). Due to this, in the new variant more than 104,050 eggs or 18.834 t of egg mass were received. The use of the proposed technological solutions contributed to some reduction in the specific cost of feed: by 329 g per average annual laying hen, by 11 g per 10 eggs and 51 g or 2.3% per 1 kg of egg mass. The total economic impact of the proposed developments amounted to UAH 34,060 or 769.2 UAH per thousand laying hens; a payback period equaled to 0.7 year, which indicates their high economic efficiency (Table 5).

Table 5. Economic efficiency of the proposed technological solutions.

Indicators	Basic variant	New variant
Additional capital investments, thousand UAH	-	18.5
Additional operating costs in the poultry house	-	13.040
Total number of eggs sold, thousands	13725.38	13829.40(+104.05)
Amount of poultry meat (live weight) sold, t	89.350	90.113(+0.763)
Revenue from the sale of additional products, thousand UAH, totally	-	49.875
including: eggs (0.45 UAH per piece)	-	46.823
meat (4 UAH per kg of live weight)	-	3.052
Economic effect, thousand UAH	-	34.060
Payback period of additional costs, years	-	0.7

Additional operating costs included: cost of electricity consumed by bactericidal lamps, a set of replaceable bactericidal lamps, phosphogypsum spent in the scrubber, salaries for servicing of additional equipment, additional depreciation and additional deductions for ongoing repairs. The installation of the air heater in the air mixer did not affect the overall fuel costs on the poultry house heating, since additional costs on the operation of this heater were offset by a similar reduction in fuel costs for the operation of the air heaters installed in the main premises of the poultry house.

The data presented in Table 5 did not consider the effect of reducing the cost of transporting, recycling litter in the new variant, application of used phosphogypsum for litter composting (as a filler) or directly as fertilizer of phosphorous enriched with nitrogen, and the effect of reducing environmental pollution. Thus, the results of the production testing fully confirmed the effectiveness and practical relevance of the proposed technological solutions to reduce microbial air pollution in the poultry house and the content of toxic gases. With the poultry is kept the premises for a long time dust, fluff, residues of feed, etc. are accumulated in it. In the process of their life, birds release gases, water vapor and litter. At the same time microflora that can cause various diseases of the poultry is concentrated in the poultry houses (Fernanda et al., 2017; Paliy et al., 2018a; Schmidt et al., 2002). Therefore, the amount of the pollutant emissions and their specific characteristics are responsible for the fact that modern poultry farms can be considered as sources that have a significant effect on the atmospheric air (Costa et al., 2012). Due to the existing problem, it is necessary to develop measures to reduce the level of air pollution in the area of exposure of poultry farms. However, it should be emphasized that air purification and decontamination are costly and should be used where appropriate and necessitated (Almuhanna et al., 2012; Kic, 2016).

The improvement of the microclimate in the poultry house (new variant) had a positive effect on productive indicators of laying hens. In the new variant, poultry survival was 1.5% higher ($P \le 0.001$), more than 2.2 eggs per initial laying ($P \le 0.05$) were obtained, and the average weight of 1 egg exceeded that of the control poultry by 0.9 g ($P \le 0.01$). Due to this, in the new variant, more than 104,050 eggs were received, which in translation for egg production amounted to 18.834 t. The feed consumption was 2.3% lower per 1 kg of egg mass in the experimental poultry house.

It is clear that the implementation of the proposed developments required some additional costs. Additional capital investments were needed for insulation (bricks with a layer of insulating material) of the air mixer chamber (room of 5.5 m long, 2.5 m wide and 3.5 m high; gas heater with a heat output of 10 kW; manufacture of a scrubber and a frame of a bactericidal device; 24 bactericidal lamps with appropriate lamps and starting-protection fittings). The total amount of these expenses amounted to 18,500 UAH.

The results obtained in real technological environment are similar to those obtained during scientific and economic experiments. Based on the results of the production testing, all the proposed technological solutions aimed at reducing the microbial contamination of the air of the poultry gas and toxic gas content in it can be recommended for introduction into poultry farms with the use of cage batteries with a belt litter removal system and built-in ducts. Based on the research conducted, practical proposals were developed and used in the preparation of the National Standard project 'Poultry Litter. Recycling into organic and organic-mineral fertilizers. Technological processes. Basic Parameters'. The social significance of the proposed developments consists in the improvement of the working conditions of the personnel and to reduction of harmful emissions into the environment. The current level of development of the poultry industry and the state of its raw material base require a fundamentally new approach to the problem of using internal resources. The essence of this approach lies in the creation and implementation of low-waste and non-waste technologies, which allow to integrate as far as possible virtually all raw materials, which are constantly formed and accumulated in poultry farms. The application of this approach is subdued to the need to eliminate the damage to the environment caused by the accumulation of waste, and to create the conditions for generating additional revenue from the sale of already recycled waste.

Conclusion

To reduce the microbial contamination and harmful gases of the air in poultry house below the maximum permissible concentrations, we suggest applying the advanced technical and technological solutions: a scrubber with phosphogypsum reagent and bactericidal device, using the cage batteries with litter removal belt conveyors and built-in ducts.

The advantages of this scheme should be summarized in the reduction of ammonia content in the air of poultry houses by 2.6 times on the first day and by 1.9 times on the fifth day in cold season and by 2.3 times and 1.7 times in transition season, respectively. We also reported the decreasing in the total weight of the litter after removal from the premises by 95 t and reducing of the transport costs. A total of 104,05o eggs or 18.834 t of egg mass more were received extra, the economic effect was 769.2 UAH per 1.000 heads, payback period of additional costs was 0.7 years. The use of the proposed technological solutions contributed to definite reduction in the specific feeding costs: by 329 g per average laying hen, by 11 g per 10 eggs, and by 51 g or 2.3% per kg of egg mass.

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