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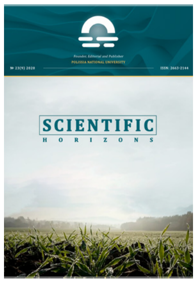

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Analytical Study of the Automatic Ventilation System for the Intake of Polluted Air from the Pigsty

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Abstract. The microclimate of a pigsty is determined by the combination of temperature, relative humidity, chemical and mechanical composition of the air, which have a significant impact on animal productivity and must be maintained within strict limits due to the physiological needs and capabilities of animals. An appropriate ventilation system has been created to ensure the removal of air from the pigsty. The purpose of the study is to establish the dependence of the operating parameters of the automatic ventilation system on the air quality in the pigsty, taking into account the permissible concentrations of gases. The developed automatic ventilation system for polluted air intake is located in the middle of the livestock house under the ceiling and consists of a central air duct, to which air intake pipes are connected. Air intake pipes are placed in the middle above each pen where animals are kept. Intake dampers with servomechanisms, temperature, humidity, and air quality sensors are installed at the inlet of the air intake pipes. The outlet of the central air intake duct is connected to the exhaust fan. Intake dampers with servomechanisms and sensors of temperature, humidity, and air quality are connected to the control unit by electrical wires. As a result of analytical studies of the automatic ventilation system for polluted air intake from a pigsty, the conditions for its effective operation have been mathematically substantiated. The developed technique and the algorithm implemented based on the Mathematica software package allows calculating the area of holes that form intake dampers with servomechanisms in the air intake pipes. The distribution of velocities in the air intake pipes and the distribution diagram of the area of holes that form intake dampers with servomechanisms in the air intake pipes are determined taking into account the design and technological parameters of the ventilation system and the distribution of the gas concentration (carbon dioxide, ammonia, and hydrogen sulphide) over the pens

Keywords: microclimate, pigsty, ventilation, automation, parameters, research, dependencies

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INTRODUCTION

The microclimate in a pigsty is determined by the combination of temperature, relative humidity, chemical and mechanical composition of the air. Each of these indicators individually has a significant impact on the animal productivity and must be maintained within strict limits due to the physiological needs and capabilities of animals. The microclimate is also affected by the technology of keeping animals, the density of their placement, the quantity and quality of bedding, the type of feeding, the species and age composition of livestock. In other words, a microclimate is a meteorological regime of closed rooms for animals, the concept of which includes temperature, humidity, chemical composition and speed of air movement, dustiness, and illumination. The optimal microclimate helps to increase animal productivity, reduce feed costs for obtaining a unit of production, which has a positive effect on the health of farm animals. The state of the microclimate depends on climatic and weather conditions, the type of pen and its enclosing structures, the level of air exchange, the perfection of the systems of ventilation, heating, sewerage, and manure harvesting [1].

A significant number of research papers are devoted to the study of the influence of microclimate on the productive qualities of pigs [2-4]. M. Kalinin [5], V. F. Lipatnikov and V. P. Stepanov [6] note that the conditions of keeping pigs during rearing significantly affect their productivity. At the same time, a significant number of researchers point out the dependence of microclimate parameters on the technical devices used to provide it [7].

In industrial animal husbandry, the creation of an optimal microclimate depends on many factors and is carried out through a number of compromises. Nowadays, there are data based on which it is possible to accurately determine those environmental factors necessary for the manifestation of genetically determined abilities of animals. However, providing a thermoneutral zone is associated with large capital investments, high energy prices, and recently requires increasing operating costs. As long as there are no significant changes in pricing, instead of forming a thermoneutral zone, it is advisable to create an optimal productive environment, which is a compromise between high production costs and the quality of livestock products. Given that the size of capital investment and operating costs can change significantly in a short time, the microclimatic conditions characteristic of an optimal productive environment also cannot remain unchanged, even taking into account the fact that the requirements of animals for their environment practically do not change for a long time [8].

Modern climate control systems in pig breeding premises include: climate control computers, temperature, humidity and gas sensors, fans, humidifiers. The heart of the microclimate control system is a computer that controls all mechanisms. The computer continuously controls the fans, changing their performance from 0 to 100%, while providing greater resistance of ventilation to changes in atmospheric pressure and less sensitivity to winds. This allows ensuring an optimal indoor microclimate and is cost-effective. At the same time, non-automatic exhaust devices (roof shafts of various configurations; shafts that draw air from manure channels) and supply devices (roof shafts, wall and ceiling vents-valves, windows [9] are also used.

The sex and age of pigs and the configuration of the pig breeding room affect the need to use a particular type of heating. The heating system is selected taking into account the availability of certain energy resources at the farm enterprise. The use of electricity and direct fuel combustion equipment is considered the most common in modern pig breeding complexes. The most economical is the use of blower heat generators. Taking into account the technological features, such systems can be used in pens for keeping boars, mating-gestating sows, and fattening pigs. Due to the generation of intense air flow, they cannot be used in nurseries and rearing pens. To provide heating of rearing pens, a ribbed general heating pipe, water heating registers such as delta tubes and water mats are most often used. In turn, infrared emitters are successfully used in nurseries. Their energy source is electricity or natural gas [10].

The purpose of the study is to establish the dependence of the operating parameters of the automatic ventilation system for the polluted air intake on the air quality in the pigsty, taking into account the permissible gas concentrations.

MATERIALS AND METHODS

Analytical studies of the automatic ventilation system for the intake of polluted air from a pigsty are carried out based on mathematical modelling of the process using the main provisions of aerodynamics and numerical calculation methods.

The Mathematica computer mathematics system was used to simplify the obtained expressions and mathematical modelling. The following provisions were adopted to develop a mathematical model of the operation of the ventilation system for polluted air intake:

– in each section of the air flow through the air ducts, part of the total pressure used to overcome the forces of pneumatic resistances is lost due to the molecular and turbulent viscosity of the moving air, the mechanical work of the resistance forces is converted into heat;

– there are two types of pneumatic resistance in an air duct: friction resistance and local resistance;

– pneumatic friction is caused by the air viscosity (both molecular and turbulent) that occurs during its movement, and is the result of the exchange of the amount of motion between molecules (in laminar motion), and between individual particles (in turbulent motion) of neighbouring air layers moving at different speeds;

– local resistances occur when a local violation of the normal flow, separation of the flow from the walls, vortex generation, and intense turbulent mixing of the flow in places where the configuration of the air duct changes or when obstacles meet and flow around. These phenomena increase the exchange of motion between moving air particles (i.e., friction), increasing energy dissipation.

The main parameters of the microclimate of pig breeding premises are regulated by the norms of technological design [11]. According to the recommendations of well-known animal technicians and veterinarians [12; 13] and the existing requirements of VNTP-APK-02.05 "Pig breeding enterprises (complexes, farms, small farms)", the technological parameters of the microclimate of premises for keeping pigs can be summarised in Table 1.

***Table 1**. Technological parameters of the microclimate of premises for keeping pigs*

Parameter	Newborn piglets	Piglets up to 8 kg	Growing	Fattening	Closed gilts	Suckling gilts
Air temperature, °C						
Maximum	33	30	20	20	18	22
Minimum	30	24	15	12	13	18
Relative humidity, %						
Maximum	60	70	70	70	70	70
Minimum	55	40	40	40	40	40
Maximum permissible air velocity, m/s						
At the minimum temperature	0.15	0.2	0.2	0.3	0.3	0.15
At maximum temperature	0.4	0.5	0.5	1	1	0.4
Permissible concentrations of gases and dust in the air						
Carbon dioxide (long-term), %	0.2					
Carbon dioxide (short-term), %	0.35					
Ammonia (long-term), mg/m^3	20					
Ammonia (short-term), mg/m^3	30					
Hydrogen sulphide, (long-term), mg/m^3	10					
Hydrogen sulphide, (short-term), mg/m^3	15					

Naturally, such microclimate parameters at ruling energy prices require high costs, but these are the most favourable conditions for the life of suckling piglets.

RESULTS AND DISCUSSION

To ensure the removal of air from the pigsty, an appropriate ventilation system has been created (Fig. 1). To substantiate the design and technological parameters of ventilation system automation, it is necessary to perform analytical studies.

Automatic ventilation system for polluted air intake (Fig. 1) is located in the middle of the livestock room under the ceiling and consists of a central air duct for air intake (1), to which the air intake pipes (2) are connected. Air intake pipes (2) are located in the middle above each pen where animals are kept. Intake dampers with servomechanisms (3) and temperature, humidity, and air quality sensors (4) are installed at the

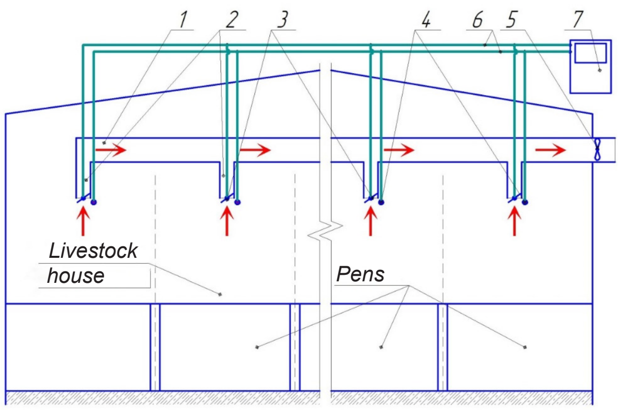

***Figure 1**. Technological scheme of automatic ventilation system for polluted air intake: 1 – central air duct; 2 – branch pipes; 3 – intake dampers with servomechanisms; 4 – temperature, humidity, and air quality sensors; 5 – exhaust fan; 6 – electrical wires; 7 – control unit*

inlet of the air intake pipes (2). The outlet of the central air duct for air intake (1) is connected to the exhaust fan (5). Intake dampers with servomechanisms (3) and temperature, humidity, and air quality sensors (4) are connected to the control unit (7) by means of electrical wires (6).

The automatic ventilation system for polluted air intake works as follows: depending on the air quality above the pens, which is determined using temperature, humidity, and air quality sensors (4) and the limit values set by the operator, the control unit (7) transmits a signal to the intake dampers with servomechanisms (3) by electrical wires (6). If the measured air quality values are less than the limit values set by the operator, the intake flap with servo drive (3) is closed. Otherwise, the intake flap with servo drive (3) opens at an angle that is directly proportional to the corresponding difference between the air quality values and the limit values. Under the action of exhaust fan (5), air is sucked into the air intake pipes (2) and is formed into a stream that moves through the central air intake duct (1) of the polluted air intake system. Then the air flow is removed from the room.

Due to the fact that certain group pens may contain different numbers of animals grouped by age, the gas concentration (carbon dioxide, ammonia, and hydrogen sulphide) located above the pens may differ (Fig. 2) [14-16]. Therefore, the automatic ventilation system for polluted air intake must adjust the air flow rate for each pen individually.

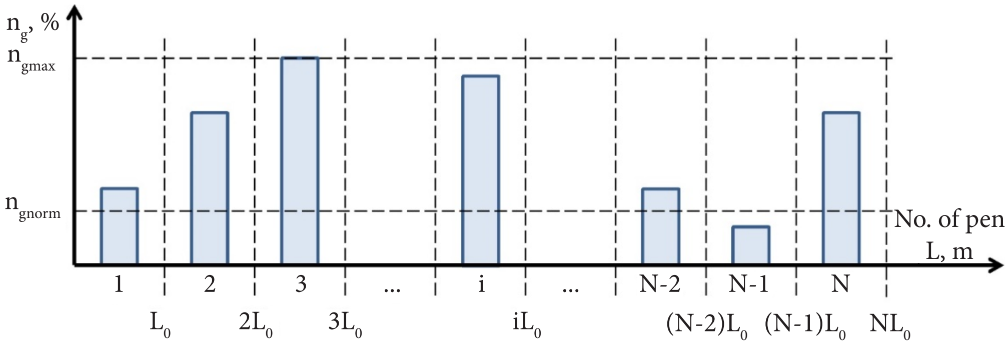

Figure 2. *Distribution of gas concentrations (carbon dioxide, ammonia, and hydrogen sulphide) ng above the pens:* *n_g – gas concentration (carbon dioxide, ammonia, and hydrogen sulphide) above the pens, %; n_{gnorm} – limit values of gas concentration in the pigsty, %; n_{gmax} – maximum value value of gas concentration above the pen, %; i – pen number; N – total number of pens; L_0 – width of the pen (provided that the geometric dimensions of all pens are the same), m*

The operation of an automatic ventilation system for polluted air intake can be mathematically represented as follows:

$$n_{gi} \leq n_{gnorm} \Rightarrow q_i = q_0$$
$$n_{gi} = n_{gmax} \Rightarrow q_i = q_{max} = q_0 + \Delta q_{max} \quad (1)$$

where $q_i = q_0 + \Delta q_i$ – volumetric air flow rates through *i-th* air intake pipe, m^3/s; q_0 – volumetric air flow rate through the air intake pipe when the servo-operated intake flap is completely closed, m^3/s; Δq_i – volumetric air flow rate through the open i-th intake flap with servo drive at a certain angle, m^3/s; q_{max} – volumetric air flow rate through the air intake pipe when the servo-operated intake flap is fully open, m^3/s; Δq_{max} – volumetric air flow rate through a fully open *i-th* intake flap with servo drive, m^3/s.

The values of air flow through the open *i-th* intake flap with a servo drive must be directly proportional to the gas concentration (carbon dioxide, ammonia, and hydrogen sulphide) over *i-th* pen:

$$\Delta q_i = k(n_{gi} - n_{gnorm}) \quad (2)$$

$$\Delta q_{max} = k(n_{gmax} - n_{gnorm}) \quad (3)$$

where k – proportionality coefficient, m^3/(c·%).

Combining equations (1)-(3), the dependence of air flow through the open *i-th* intake flap with servo drive from the gas concentration (carbon dioxide, ammonia, and hydrogen sulphide) over *i- th* pen is obtained:

$$q_i = \begin{cases} q_0 + \dfrac{\Delta q_{max}}{n_{gmax} - n_{gnorm}}(n_{gi} - n_{gnorm}), n_{gi} > n_{gnorm}, \\ q_0, n_{gi} \leq n_{gnorm} \end{cases} \quad (4)$$

In turn, the volume flow rate of air through the open i-th air intake flap with servo drive at a certain angle directly proportional to the area of the opening σ_i, and air velocity V_i:

$$q_i = q_0 + \sigma_i V_i \quad (5)$$

Expressing from (5) σ_i and substituting in (4):

$$\sigma_i = \begin{cases} \dfrac{1}{V_i}\dfrac{\Delta q_{max}}{n_{gmax} - n_{gnorm}}(n_{gi} - n_{gnorm}), n_{gi} > n_{gnorm}, \\ 0, n_{gi} \leq n_{gnorm} \end{cases} \quad (6)$$

In accordance with previous studies [17-18], it was found that under the condition of uniform placement of air intake pipes and their identical diameter, the velocity field is deformed, which consists of air velocities from each hole V_i.

The deformation of the velocity field consists in the fact that the air velocity field has a skewed profile: from the axis of the central air duct for air intake in the direction of the opening, an increase in speed is observed, and in the opposite direction (a wall without a hole) – a decrease. The static air pressure changes in the cross-section in the opposite order: it is the smallest in the hole and continuously increases in the direction opposite to the wall of the hole. When moving from one cross-section to another, the average air velocity, dynamic average and average pressure change.

In the direction from the beginning to the end of the central air intake duct (opposite to the air flow), the average speed decreases. Thus, the dynamic pressure will decrease in such a direction that it is opposite to the direction of air flow by a certain amount, which, according to the law of conservation of energy, will turn into static pressure. This value of dynamic pressure is called "released dynamic pressure". Due to the released dynamic pressure, the static air pressure inside the central air intake duct increases in the opposite direction of the flow. However, it will be spent in the same direction on overcoming friction and local resistance. If the released dynamic pressure is greater than the pressure losses on friction and local resistances, then the static pressure will eventually increase, and if it is less than these pressure losses, then the static pressure will decrease. If the released dynamic pressure is equal to the pressure loss, then the static air pressure inside the central air intake duct will remain unchanged. Thus, the nature of the change in static air pressure inside the central air intake duct depends entirely on the ratio of released dynamic pressure and pressure losses. Taking into account the above, equation (6) needs to be clarified taking into account the non-uniformity of the air flow velocity distribution, which occurs due to pressure losses.

Central air duct for air intake of constant cross-section length L (Fig. 3) has a perimeter R and cross-sectional area F. Along the air duct in its side surface, N air intake pipes is evenly distributed. The area of the openings of the air intake pipes is different. The air flow rate at the end of the duct is equal to w_k.

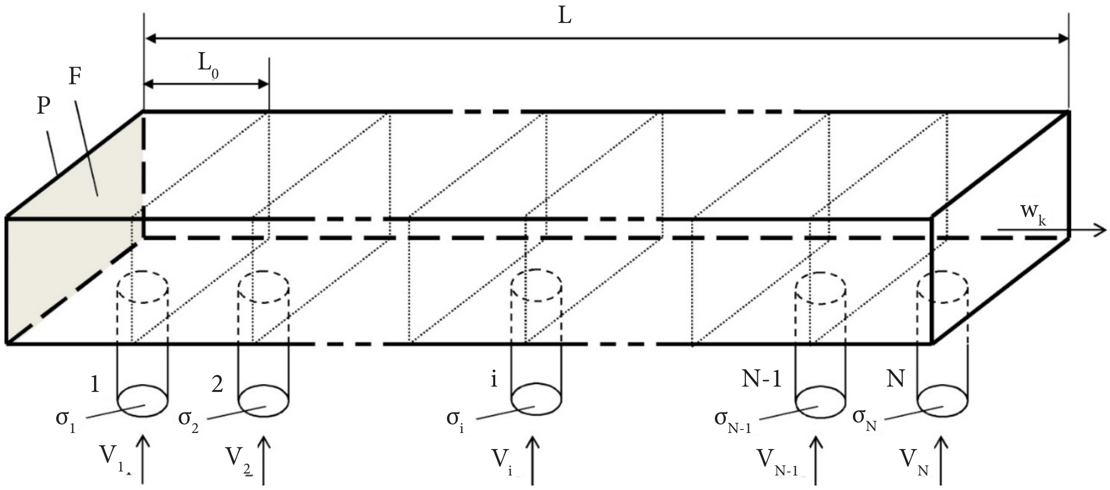

***Figure 3**. Design scheme of the central air duct for air intake*

It is necessary to determine how the areas of the openings of the air intake pipes should change along the length of the central air duct to ensure that air is sucked into the openings in accordance with the equation (4). TIt is necessary to number all the holes in the direction of the air flow and draw cross-sections 1-1, 2-2,..., *i-i*, (*N-1*)-(*N-1*), *N-N* after each hole.

Air intake rate in i-th air intake pipe opening:

$$V_i = \mu\sqrt{\frac{2}{\rho}(p_a - p_i)} \quad (7)$$

where ρ – air density, kg/m^3; p_i – pressure in *i-th* opening of the air intake pipe, Pa; p_a – atmospheric pressure, p_a=101,325 Pa; μ – coefficient of friction of the hole, μ=0.65 [19].

Since the volume is limited by *i-th* and *i-1-th* sections and walls of the central air duct for air intake, the equation of the amount of motion in projections on the axis of the air duct has the form:

$$p_{i-1}F - p_iF - \tau_{i-1}PL_0 = \frac{\rho F w_i^2}{2} - \frac{\rho F w_{i-1}^2}{2} \quad (8)$$

$$\tau_{i-1} = \frac{\lambda}{4}\frac{\rho w_{i-1}^2}{2} \quad (9)$$

where L_0 – distance between the axes of two adjacent holes, m; λ – coefficient of friction resistance, λ=0.01717 [20]; w_i – air velocity through *i-th* cross-section, m/s.

Substituting equation (9) into (8) and dividing all terms of the equation by F, obtain:

$$p_{i-1} - p_i - \frac{\lambda\rho PL_0 w_{i-1}^2}{8F} = \frac{\rho w_i^2}{2} - \frac{\rho w_{i-1}^2}{2} \quad (10)$$

With uniform air distribution:

$$w_i = w_k \frac{i}{N}, \; w_{i-1} = w_k \frac{i-1}{N}, \; \Delta q \frac{q_k}{N}_{max} \tag{11}$$

Substituting in the last equation w_i and w_{i-1}:

$$p_{i-1} = p_i + \frac{\rho w_k^2}{2} \frac{1}{N^2} \left[\left(\frac{\lambda P L_0}{4F} - 1 \right) (i-1)^2 + i^2 \right] \tag{12}$$

According to equation (8) for the end of the central air intake duct:

$$p_N = \frac{\rho w_k^2}{2} \tag{13}$$

The air flow rate at the end of the central air intake duct is determined by the equation (14):

$$q_k = w_k F \tag{14}$$

from here:

$$w_k = \frac{q_k}{F} \tag{15}$$

The dependence of (12) and (13), taking into account (15), takes the form:

$$p_{i-1} = p_i + \frac{\rho q_k^2}{2F^2} \frac{1}{N^2} \left[\left(\frac{\lambda P L_0}{4F} - 1 \right) (i-1)^2 + i^2 \right] \tag{16}$$

$$p_N = \frac{\rho q_k^2}{2F^2} \tag{17}$$

Substituting the pressure value according to equation (16) into (7):

$$V_{i-1} = \mu \sqrt{\frac{2}{\rho} \left(p_a - p_i - \frac{\rho q_k^2}{2F^2} \frac{1}{N^2} \left[\left(\frac{\lambda P L_0}{4F} - 1 \right) (i-1)^2 + i^2 \right] \right)} \tag{18}$$

Substituting (18) into (6), an equation is finally obtained for calculating the area of the opening formed by the intake flap with a servo drive in the air intake pipe:

$$\sigma_i = \begin{cases} \dfrac{\dfrac{\Delta q_{max}}{n_{gmax} - n_{gnorm}} (n_{gi} - n_{gnorm})}{\mu \sqrt{\dfrac{2}{p} \left(p_a - p_i - \dfrac{p q_k^2}{2F^2} \dfrac{1}{N^2} \left[\left(\dfrac{\lambda P L_0}{4F} - 1 \right) (i-1)^2 + i^2 \right] \right)}} & n_{gi} > n_{gnorm} \\ 0, n_{gi} \leq n_{gnorm} \end{cases} \tag{19}$$

The methodology developed above and the algorithm implemented on its basis are executed in the Mathematica software package.

Taking the structural and technological parameters of the ventilation system for polluted air intake (L=42 m; P=1.25 m; ρ=1.27 kg/m^3; q_k=1.5 m^3/s; F=0.126 m^2; μ=0,025; p_a=101325 Pa; λ=0.01717; n_{gnorm}=10%) and distribution of gas concentrations (carbon dioxide, ammonia, and hydrogen sulphide) ng above the pens (Fig. 4) the speed distribution in the air intake pipes is determined (Fig. 5).

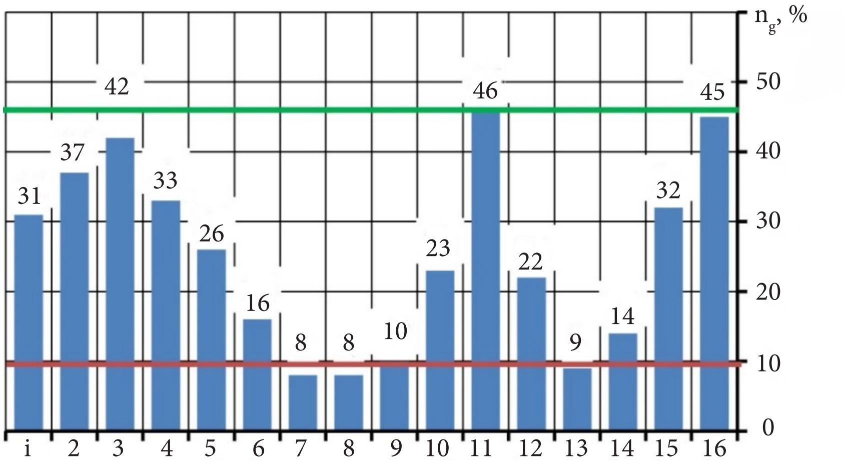

Figure 4*. Distribution of gas concentration ng above the pens*

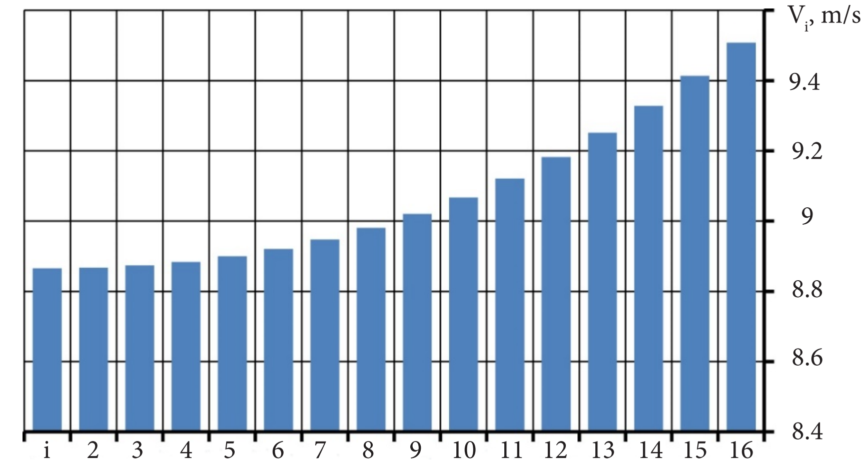

Figure 5. *Velocity distribution V_i in the air intake pipes*

Analysing Figure 5, it can be argued that the speed in the air intake pipes gradually decreases from 9.5 m/s to 8.8 m/s in the direction opposite to the air flow. Given the resulting velocity distribution V_i in the air intake pipes (Fig. 5) and the gas concentration distribution is accepted ng above the pens (Fig. 4) taking into account equation (19), a diagram of the distribution of the area of holes formed by intake dampers with servomechanisms in the air intake pipes is obtained (Fig. 6). For comparison, Figure 6 shows a diagram of the hole area distribution without taking into account the velocity distribution V_i in the air intake pipes.

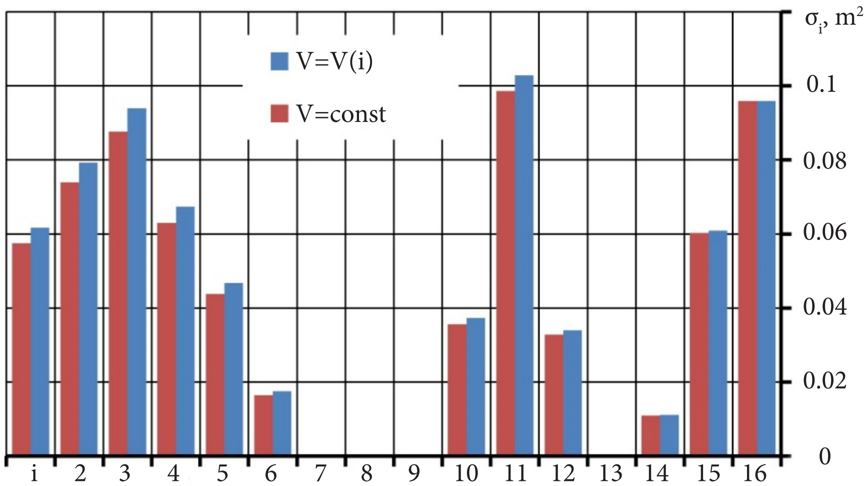

Figure 6. *Velocity distribution V_i in the air intake pipes*

Analysis of Figure 6 shows that given the velocity distribution $V=V_i$ of the control unit of the automatic ventilation system for polluted air intake, it is possible to more accurately adjust the intake dampers with servomechanisms. This allows fulfilling the specified condition (4).

CONCLUSIONS

An increase in pig productivity can be achieved in various ways. The most effective of them is to create a favourable microclimate in the pens where pigs are kept. A favourable microclimate is achieved in various ways, but the simplest is the arrangement of professional ventilation. Proper design of livestock facilities and equipment with ventilation systems prevents cases of dangerous viruses and, as a result, improves the quality and safety of pork.

As a result of analytical studies of the automatic ventilation system for polluted air intake from a pigsty, the conditions for its effective operation have been mathematically substantiated. The developed technique and the algorithm implemented based on the Mathematica software package allows calculating the area of holes that form intake dampers with servomechanisms in the air intake pipes.

Taking the structural and technological parameters of the ventilation system for polluted air intake ($L, P, \rho, q_k, F, \mu; p_d, \lambda; n_{gnorm}$) and distribution of gas concentrations (carbon dioxide, ammonia, and hydrogen sulphide) n_g the speed distribution in the air intake pipes above the pens V_i is determined and a diagram of the hole area distribution σ_i, which form intake dampers with servomechanisms in the air intake pipes.

Taking into account the speed distribution $V=V_i$

of the control unit of the automatic ventilation system for polluted air intake, it is possible to more accurately adjust the intake dampers with servomechanisms. This allows fulfilling the set condition for the dependence of air flow through the open *i-th* air intake flap with servo drive depending on the gas concentration (carbon dioxide, ammonia, and hydrogen sulphide) over *i-th* pen.

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Аналітичні дослідження автоматичної вентиляційної системи забору забрудненого повітря свинарського приміщення

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Анотація. Мікроклімат свинарського приміщення визначається сукупністю температури, відносної вологості, хімічного та механічного складу повітря, які мають суттєвий вплив на продуктивність тварин і мають підтримуватися в суворих рамках, обумовлених фізіологічними потребами і можливостями тварин. У рамках зазначеного для забезпечення відведення повітря з приміщення свинарника створена відповідна вентиляційна система. Метою досліджень є встановлення залежності режимних параметрів автоматичної вентиляційної системи забору забрудненого повітря від якості повітря у свинарнику з урахуванням допустимих концентрацій газів. Розроблена автоматична вентиляційна система забору забрудненого повітря розміщена в середині тваринницького приміщення під стелею і складається з центрального повітропроводу для забору повітря, до якого приєднанні патрубки для забору повітря. Патрубки для забору повітря розміщенні посередині над кожним станком, де утримуються тварини. На вході патрубків для забору повітря встановлені забірні заслінки із сервоприводами і датчики температури, вологості та якості повітря. Вихід центрального повітропроводу для забору повітря приєднано до витяжного вентилятора. Забірні заслінки із сервоприводами і датчики температури, вологості та якості повітря по засобах електричних проводів 6 приєднані до блока керування. У результаті аналітичних досліджень автоматичної вентиляційної системи забору забрудненого повітря свинарника математично представлено умову її ефективної роботи. Розроблена методика і реалізований на основі неї алгоритм у програмному пакеті Mathematica дозволяє розраховувати площі отворів, які утворюють забірні заслінки із сервоприводами у патрубках для забору повітря. Приймаючи конструкційно-технологічні параметри вентиляційної системи забору забрудненого повітря і розподіл концентрації газів (вуглекислого газу, аміаку і сірководню) над станками визначено розподіл швидкостей у патрубках для забору повітря і діаграму розподілу площі отворів, які утворюють забірні заслінки із сервоприводами у патрубках для забору повітря

Ключові слова: мікроклімат, свинарник, вентиляція, автоматизація, параметри, дослідження, залежності