Maintaining microclimate in livestock buildings by anaerobic processing of own materials (Manure)

Ryskul Kasymbekov[1,*], *Nazgul* Temirbayeva[2], *Ilyaz* Turduyev[3], *Ysman* Osmonov[2], *Janar* Osmonov[2], *Oskon* Osmonov[2], and *Ainagul* Zhusubaliyeva[4]

[1]The Machinery researching and Automatics Institute of Kyrgyz Republic National Academy of Science, Department of innovations, new equipment and technologies, Bishkek, the Kyrgyz Republic
[2]The Kyrgyz National Agrarian University, Electrification and automation of agriculture, Bishkek, the Kyrgyz Republic
[3] Osh Technological University, Department of Electro Supply. Osh, the Kyrgyz Republic
[4] Osh State University, Department of Specialized Disciplines, Osh, the Kyrgyz Republic

Abstract: Environmental problems with a growing trend and the shortage of traditional fuel and energy resources make it relevant to use alternative renewable energy sources in agriculture. From this position, the processing of manure as an energy renewable raw material using biogas technology, which is based on the process of methanogenesis, is able to autonomously provide remote small farms with energy – biogas, biofertilizer and electricity. The results of experimental studies have shown: the speed of air entering the barn with 150 heads of cattle varies across the width of the room at different sections, in the range of 0.1 ... - 0.1 m / s, along the length in the range of 0.2 ... -0.2 m / s from the standard temperature, air velocity (0.25 m / s); the air temperature across the width of the barn in different sections along the height varies within 3 ... -3 ° C from the standard temperature (+ 12 ° C), the gas composition within five hours varies within: ammonia (0.1 ... 0.23 mg / kg); carbon dioxide (0.21-0.26 mg/kg); hydrogen sulfide (0.01-0.025 mg/kg), which meets the regulatory requirements of the microclimate of the premises for cattle.
Keywords: microclimate, manure, biogas, methanogenesis, biofertilizer, livestock buildings.

1. Introduction

One of the priority issues of the agricultural science is providing alternative energy for animal farming production processes based on renewable resources. In these terms, using the energy of manure (as own renewable materials) by anaerobic fermentation is getting wider as the livestock of agricultural animals grows and intensive technologies of livestock management propagate. The annual growth of all types of agricultural animals and birds (except for pigs) in the Kyrgyz Republic is about 4% on average and their species composition is improving.

* Corresponding author: kubansultanovich@gmail.com

Modern technologies of livestock management demand certain microclimate in livestock buildings complying with zoo-hygienic standards, which can be provided and supported by engineering systems: manure removal, ventilation, heating, illumination, heat- and water-proofing of the floor and enclosing structures, maximum use of automatic microclimate control parameters, etc. [2], [3].

It is complicated to ensure microclimate in livestock buildings because they have a lot of physical-mechanical and chemical-biological factors (for example, more than 30 types of noxious gases) and each individual factor also affects animals causing deep negative changes in the body and reducing their productivity. The animal productivity up to 30% is defined by the condition of microclimate parameters in a livestock building [4]. This requires differentiated approaches to ensuring microclimate taking into account the species, type, gender, age, and individual features of animals.

Developed countries show a trend in reducing the livestock population and increasing their productivity. This trend in the husbandry has environmental, social and economic significance [5]. In this issue, the contribution of optimal microclimate in livestock buildings is obvious and, as said above, may reach 30%.

Primary engineering issues in ensuring microclimate in livestock buildings are related with removal and processing of manure and deficient use of heating and ventilation equipment. The analysis of research papers, physical-mechanical properties and chemical composition of various types of manure and their removal and processing methods shows that the least intensive and most profitable is to use fresh manure over as short period as possible. In these terms, it seems reasonable to use the biogas technology in the livestock building where the biogas unit (as process equipment) can complete the process of manure removal and processing in order to obtain valuable products: biogas, biomanure, and biofuel for power generation.

In this configuration, the proposed process scheme of manure removal and processing has the following sequence: manure ditches – horizontal conveyor – accumulating tank – inclined transporter-bioreactor – biomanure discharge hatch. This scheme prevents labor-intensive processes such as manure loading and transportation to the storage site or in the field, improves unsanitary conditions in and around the livestock building by processing fresh manure before its decomposition. In technical terms, this scheme enables using an accumulating tank to prepare raw materials to charging into the bioreactor where the primary requirement is related with the recommended humidity of raw materials (85-92%) while the inclined part of the manure-removal conveyor can be used to feed the raw materials to the bioreactor by changing the conveyor chain speed and its incline angle. Electric energy generated by a co-generating unit that can use biogas as fuel (as an alternative type of energy) will be used in husbandry production processes, namely to provide microclimate in livestock buildings. This renewable energy generation and use system complies with the power supply, autonomation and environmental protection requirements.

Ventilation and heating systems used in livestock buildings to provide microclimate in them are energy-intensive, consume up to 40% of power (out of total), which is the primary reason for inefficiency of these systems [8], [9].

Taking into account the today's condition and development perspective of livestock management where the potential of using the biomass grows annually (in Kyrgyzstan, this potential being about 210 mln m^3 biogas, 5.4 mln tons of biomanure and about 214 mln m^3 of prevented emissions of greenhouse gases annually [10], [11], [12]), the relevance, environmental, social and economic significance of this issue, the goal and aims of the research have been formulated.

The research is aimed at developing an autonomous system of maintaining microclimate in a livestock building by anaerobic processing of own materials (manure) and substantiating the selection of automatic control actuators.

Goals of the research:

- analysis and problem statement;
- development of a process scheme for autonomous support of microclimate in a livestock building (a cowshed of 150-200 animals);
- selecting automatic control actuators;
- experimental researches.

2. Materials and methods

The research has been carried out in a livestock building (a cowshed) of the Kelecheck cooperative farm (the Kyrgyz Republic, Chüy region) containing 150 cattle animals.

The process scheme for maintaining microclimate in the livestock building is given in Figure 1 [13].

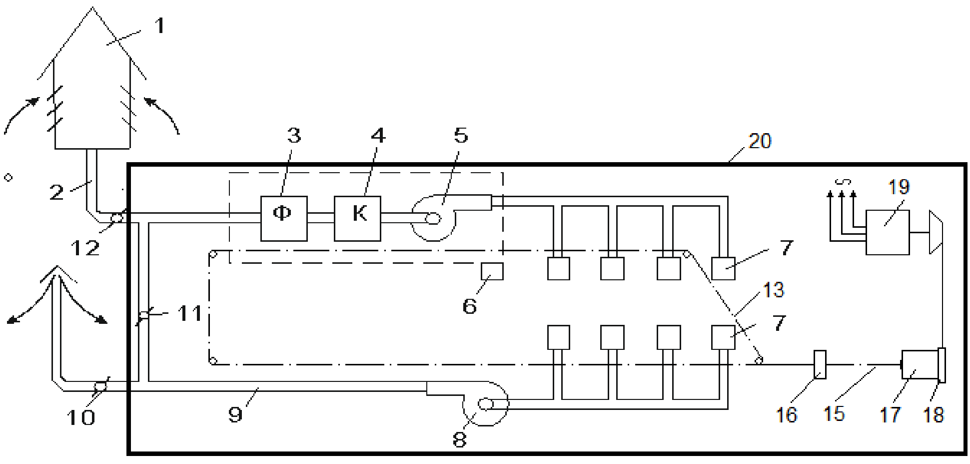


Fig. 1. Process scheme for maintaining microclimate in the livestock building: 1 – air intake; 2, 9 – air ducts; 3 – filter; 4 – heater; 5, 8 – RH and LH fans; 6 – ionizer; 7 – nozzles; 10, 11, 12 – valves; 13 – groove; 14 – lateral (horizontal) conveyor; 15 – inclined conveyor; 16 – accumulating tank; 17 – biogas unit; 18 – gas receiver; 19 – co-generator; 20 – cowshed. (Compiled by authors)

The system for maintaining microclimate in the livestock building operates as follows. Only the ventilation device operates in warm seasons (air temperature +10 °C and above). Fresh air is fed to the cowshed (Figure 1) via air intake 1, air duct 2, control valve 12, filter 3 and nozzles 7 using RH fan 5. The air taken from the cowshed using LH fan 8 is discharged to the outdoors via valve 10. Air supply to the building depending on the air temperature is controlled by valve 12. There is no air recirculation in warm seasons. Valve 11 is closed. In cold and transient periods when the air temperature is +10°C and below, the system enables a heater (4) and air circulation. To this end, the air taken from the cowshed is partially or completely supplied back to the premise via valve 11 using LH fan 8 and RH fan 5. Valve 12 can be partially opened and valve 10 is fully closed. In case of no harmful substances and microbial flora in the air, the air from the building is used for recirculation and valve 12 is fully closed.

The primary function of the system is to ensure equal amount of air supplied to the cowshed and the amount of the removed air. Operational expenses will be minimal if the condition of the air supplied to the cowshed will be maintained at the level of minimal permitted enthalpy in cold seasons and of maximum permitted enthalpy in warm seasons. This is the primary criterion of maintaining microclimate in the cowshed.

The systemic analysis has identified the following subsystems [14] (Fig. 2):

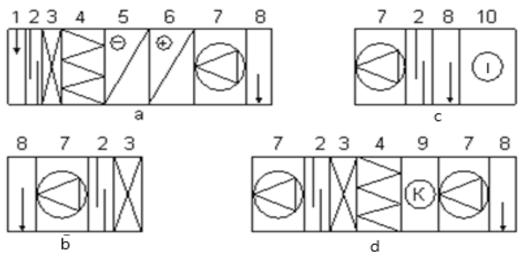
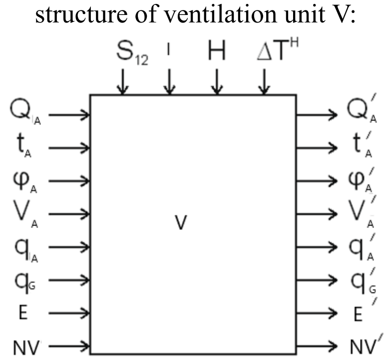
Subsystems	Subsystem components
Supply (a) Exhaust (b) Ionization section (c) Recirculation section (d)	

Fig. 2. Subsystems maintaining microclimate in the cowshed: 1 – air intake; 2 – air ducts; 3 – air valves; 4 – supply filter; 5 – cooling section; 6 – heating section; 7 – fan; 8 – nozzles; 9 – heater; 10 – ionizer. (Compiled by authors)

The system maintaining microclimate in the cowshed as a control object has two options with input and output parameters, respectively, depending on the ambient air temperature (Fig. 3):

System option	Input and output parameters
option 1 (only ventilation unit operates)	structure of ventilation unit V: 
option 2 (when ventilation-heating unit operates)	structure of ventilation-heating unit V/K

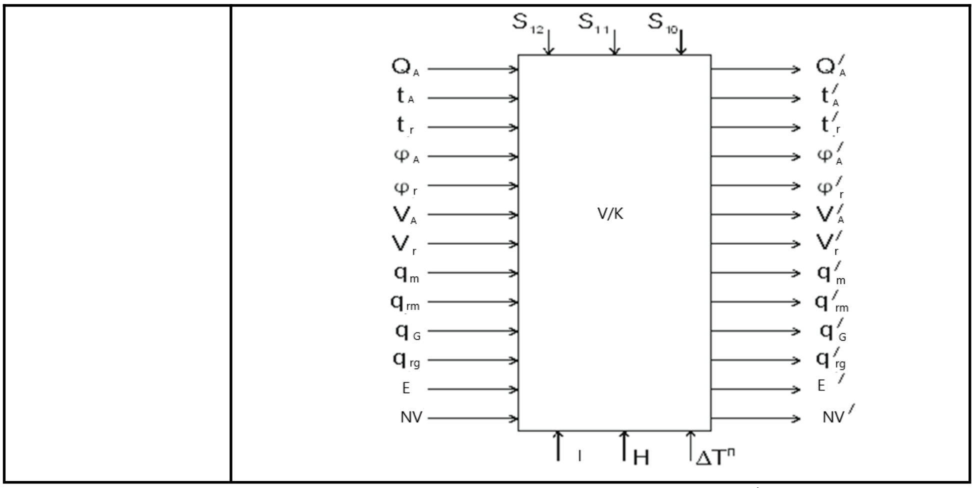


Fig. 3. Structure of ventilation (V) and ventilation-heating unit (V/K): Q_A, $Q^{/}_A$ are supply and exhaust air flow rates, m^3; t_A, $t^{/}_A$ – are supply and exhaust air temperatures, ^{0}C; φ_A, $\varphi^{/}_A$ are supply and exhaust air humidities, %; V_A, $V^{/}_A$ are supply and exhaust air velocities, m/s; q_m, $q^{/}_m$ are mechanical impurities in supply and exhaust air, mg/m^3; q_g, $q^{/}_g$ are gas content in supply and exhaust air, mg/m^3; S_{12} is valve 12 position; I is the air ionization (ozonation) rate; H is the manure removal rate; ΔT^u is the temperature difference in the cowshed, ^{0}C; E is electric energy, kW; $E^{/}$is power consumption, kW·h; NV is noise and vibration, dB; $NV^{/}$ is noise and vibration level, dB; Q^{h1} is the heater power, kJ/h; t_r, $t^{/}_r$ is the recirculation air temperature upstream and downstream of the heater, ^{0}C; φ_r, $\varphi_r^{/}$ is the recirculation air relative humidity upstream and downstream of the heater, respectively, %; V_r,$V^{/}_r$ is the recirculation air rate upstream and downstream of the ventilation-heating unit, respectively, m/s; q_{rm}, $q^{/}_{rm}$ is the mechanical impurities of recirculation air upstream and downstream of the heater, respectively, mg/m^3; q_{rg}, q_{rg} are recirculation air gas content upstream and downstream the unit, mg/m^3; S_{11} is valve 11 position; S_{10} is valve 10 position; ΔT^n is the temperature rise in the cowshed, ^{0}C. (Compiled by authors)

The controlling parameters in these structures are S_{10}, S_{11}, S_{12}. Parameters having disturbing action include Q_A, t_A, φ_a, V_a, I, H, t_r, $t^{/}_r$, V_r, $\upsilon^{/}_r$, q_{rm}, $q^{/}_{rm}$, q_{rg}, $q^{/}_{rg}$.

Both options of the microclimate maintenance system are permanent air flow rate systems depending on the required air exchange rate. The required air exchange rate in the cowshed is defined taking into account regulatory requirements to heat, moisture and gas content.

In the first option (when the ambient air temperature is +10°C and above), the supply air will need to be fed (Q^T_A) using the ventilation unit in order to remove heat generated by animals, in the following amount:

$$Q^T_A = \frac{Q_{ex}}{\rho \cdot C(t^{/}_{в} - t_a)},\ m^3/h, \tag{1}$$

where Q_{ex} is the excessive heat supply in the cowshed, kJ/h;

ρ is the supply air density, kg/m^3;

C is the specific heat capacity of air, kJ/(kg°C).

Apart from heat, moisture is generated in the cowshed when cows exhale. To purge moisture, supply air Q^A_A will be required in the following amounts:

$$Q_A^A = \frac{W}{\rho(\varphi_A^/ - \varphi_A)},\ m^3/h, \quad (2)$$

where W is the excessive moisture in the cowshed, kg/h;

Gases are emitted in livestock buildings (ammonia, methane, hydrogen sulfide, etc.), which are removed by a ventilation unit providing the following air flow rate Q_A^G;

$$Q_A^A = \frac{G}{q_g^/ - q_g},\ m^3/h, \quad 3)$$

where G is the gas emission in the cowshed, mg/h.

Equations (1), (2) and (3) are primary in calculating the system maintaining microclimate in the cowshed according to the first option.

Condition:

$$\frac{W}{(\varphi_A^/ - \varphi_A)} = \frac{Q_{ex}}{(t_A^/ - t_A)}, \quad (4)$$

is necessary to keep the defined air temperature and humidity in the cowshed.

According to the primary process criterion of maintaining microclimate in the cowshed, the minimal and maximum permitted enthalpy is defined when mixing air Q_{A1} *having parameters* t_1, φ_1, h_1 with air Q_{A2} *having parameters* t_2, ϕ_2, h_2, which is valid for option 2:

$$t_{ma} = \frac{Q_{a1} \bullet t_1 + Q_{a2} \bullet t_2}{Q_{a1} + Q_{a2}}, \quad (5)$$

$$\varphi_{ma} = \frac{Q_{a1} \bullet \varphi_1 + Q_{a2} \bullet \varphi_2}{Q_{a1} + Q_{a2}}, \quad (6)$$

$$h_{ma} = \frac{Q_{a1} \bullet h_1 + Q_{a2} \bullet h_2}{Q_{a1} + Q_{a2}}, \quad (7)$$

where t_{am} is the mixed air temperature, °C;

φ_{ma} is the mixed air relative humidity, %;

h_{ma} is the mixed air enthalpy (amount of heat containing the moisture air volume whose dry part weighs 1 kg), kJ/kg.

Enthalpies at 0 °C are taken as the starting point for dry and moist air enthalpies. Then the moist air enthalpy is the sum of dry and vapor enthalpies [15]:

$$h_a = m_d \bullet h_d + m_v \bullet h_v, \quad (8)$$

where, h_m, h_d, h_v are the enthalpies of moist, dry air and vapor, respectively, kJ/kg;

m_d, m_v is the dry air and vapor weight, respectively, kg.

The actual air enthalpies help finding the heating and cooling efficiency of the ventilation heating unit. To do it, let us make some mathematical transformations of dependency (8):

$$\frac{h_A}{m_d} = h_d + \frac{m_v}{m_d} \bullet h_v = h_d + \varphi \cdot h_v, \qquad (9)$$

where $\varphi = \frac{m_v}{m_d}$ is the moist air humidity, %.

Dry air enthalpy h_d is found using the specific heat capacity of dry air C_d (kJ/kg·K):

$$h_d = C_d \bullet t_d, \qquad (10)$$

Water vapor enthalpy h_v as a specific unit equals:

$$h_v = z_0 + C_v \cdot t_v, \ \frac{J}{kg}, \qquad (11)$$

where z_0 is the latent heat of water evaporation at 0°C (z_0=2500 kJ/kg);
C_v is the specific heat capacity of water vapors (C_v = 1.86 kJ/(kg·K)).

Taking into account dependencies (9) and (10), dependency (8) is as follows:

$$h_A = C_d \bullet t_d + \varphi(z_0 + C_v \bullet t_v), \qquad (12)$$

Hence, the heating and cooling efficiency of the ventilation heating unit is found as follows:

$$Q = Q_a^m\left(h_{a2} - h_{a1}\right), \ kJ/h, \qquad (13)$$

where Q_a^m is the air mass flow rate, kg/h;
h_{a2}, h_{a1} is the initial and final air enthalpy, kJ/kg.

The mathematical description of the system maintaining microclimate in a livestock building helped selecting the algorithmic structure of the system (dynamic models) and individual elements based on link analysis of input and output parameters and selecting the most relevant out of them.

The mathematical description of option 1 of maintaining microclimate in a livestock building can be represented in general form:

$$Q_a \pm (\Delta Q_a)P = \mathfrak{f}_1\left(t'_в, \varphi'_a, \upsilon'_a, q'_m, q'_G\right) = \mathfrak{f}_2 \sum\left(t'_a - \Delta t_a\right),$$

$$\left(\varphi'_a - \Delta\varphi_в\right), \ (\upsilon'_a + \Delta\upsilon_a), (q'_m - \Delta q_m\Big), (q'_G - \Delta q_G), \qquad (14)$$

Here, $Q_A \pm (AQ_A)P$ describes the required air exchange in the cowshed with permitted deviation $\pm\Delta Q_d$ and probability *P*. Function $\mathfrak{f}_1$ describes the link between cowshed properties with parameters formed on its surface (internal walls, ceilings, etc.). Function $\mathfrak{f}_2$ describes principles of forming each the researched parameters on the cowshed surface.

The mathematic description of function $\mathfrak{f}_2$ is as follows:

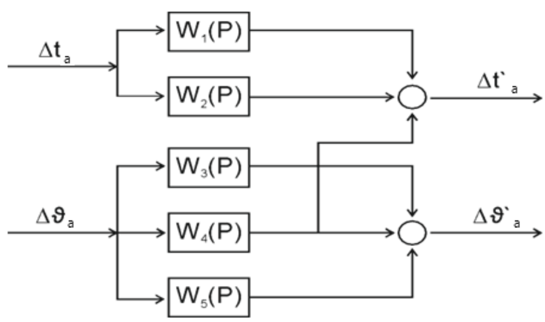
$$f_2 = hF\left(t_a^1 + \Delta t_a\right) = C_0 \int_1^{\upsilon} \Delta t_a^{\upsilon} \cdot dV \qquad (15)$$

where h is the coefficient defining the intensity of heat exchange between unit of surface F and ambient air, W /(m^{2}·^{0}C);

C_0 is the specific volumetric heat capacity of the parameters (air in this case), J/ (m^{2}·^{0}C);

Δt_a^{υ} defines the principle of parameter (temperature) distribution over the cowshed in time.

Equations (14) and (15) are represented as dynamic models that show gains on input and output parameters relative to the standardized values. The dynamic models are used as linear models of control channels depending on disturbing parameters (Fig. 4) [16, 17, 18]:

<table>
<tr><th>System option</th><th>Dynamic models of system</th></tr>
<tr><td>option 1</td><td>ventilation unit model


Control valve model


Manure removal rate model


</td></tr>
</table>

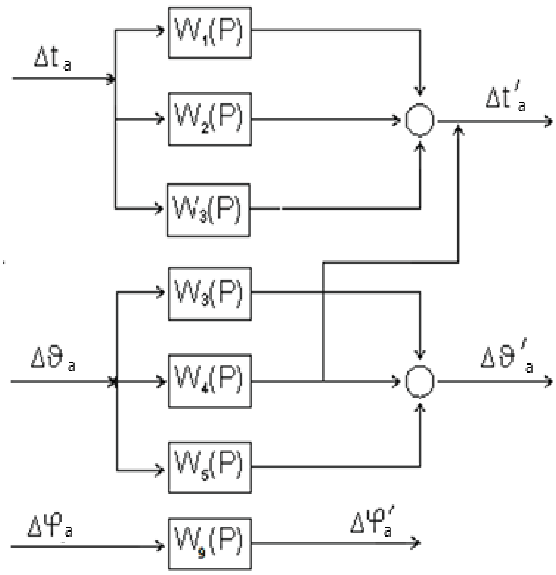
<table>
<tr><td>option 2</td><td>Ventilation-heating unit model

Control valves models
</td></tr>
</table>

Fig. 4. Dynamic models of the system: Δt_A, Δt are air temperature gains; $\Delta\vartheta_a$, $\Delta\vartheta_a^{/}$ is the air velocity gain; $W_1(P)$ is the change in supply air temperature with probability P; $W_2(P)$ is the change in cowshed air temperature with probability P; $W_3(P)$ is the degree of cowshed air treatment from noxious gases with probability P; $W_4(P)$ is the change in exhaust air temperature with probability P; $W_5(P)$ is the degree of cowshed air treatment from mechanical impurities with probability P. $\Delta Q_a^{/}$ is the air flow rate gain; $W_6(P)$ is the change in air exchange (in warm period) in the cowshed with probability P; H is the rod travel of valve 12; Δq_G is the gain in content of noxious gases; $W_7(P)$ is the change in the cowshed gas content with probability P; K is the manure removal rate; $W_8(P)$ is the change in the recirculation air temperature with probability P; $W_9(P)$ is the change in relative air humidity in the cowshed with probability P; $Q_r^{/}$ is the gain of recirculation air flow rate; $W_{10}(P)$ is the change in air exchange (in cold period) in the cowshed with probability P; H is the rod travels of valves 10, 11, 12. (Compiled by authors)

Option 2 dynamic models (when the ventilation-heating unit operates) are made similar to option 1.

The thermodynamic model of supply air parameters that represents a multidimensional function and microclimate parameters in the maintained building (cowshed) in *d-h* diagram is shown in Figure 5 [19].

The value of ΔT^S that depends on the method of air supply to the cowshed, the building volume, the air exchange rate and air infiltration is 3 to -3°C around the standard temperature (12°C), which is permitted for cattle.

The ratio of temperatures t_{sup}, t_c and t_{sp} is evaluated by the coefficient:

$$m = \frac{t_c - t_{sup}}{t_{sp} - t_{sup}} \qquad (16)$$

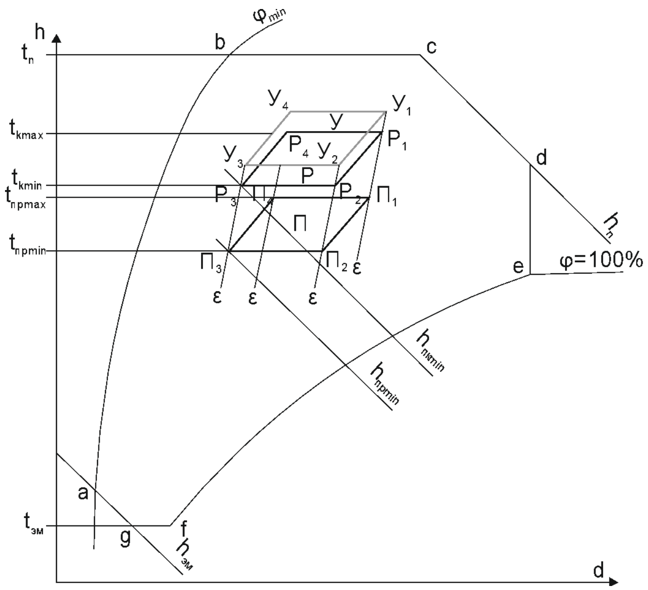


Fig. 5. The thermodynamic model of the cowshed in *d-h* diagram. (Compiled by authors)

Equipment for cowshed microclimate control automation includes: controller *Vision V120*; ambient air temperature sensors (*TGR3/PT1000*), cowshed air temperature sensors (*TGKH1/PT1000*), filter and fan temperature difference sensors (*DR8–500*); actuators for control over control valves (electrical actuator *SGX GZ*), for control over electrical damper on the air intake (electrical actuator w/ sensor *GCA326/1E*).

Since the modeling object is the internal cowshed volume that makes the supply air temperature stabilization circuit, the most suitable model is the transfer function. In a general form, the transfer function is defined as a ratio of Laplace transformation on input and output signals taking into account properties of this transformation;

$$W(P) = \frac{L\{У(t)\}}{L\{V(t)\}} = \frac{Y(P)}{V(P)} = \frac{\sum_{j=0}^{na} A_j \cdot pb}{\sum_{j=0}^{na} \alpha_j \bullet p^i} \qquad (17)$$

where *L {...}* is the Laplace transformation symbol;
P is the complex variable.

The temperature stabilization circuit transfer function including the supply air valve is as follows:

$$W_0 = \frac{K_1 \bullet K_2}{(t_A \cdot p+1)\cdot(t_A^{/} \cdot p+1)} \qquad (18)$$

where K_1, K_2 are supply air valve parameters.

PI-controller transfer function:

$$W_r = К_r \frac{(t_u \cdot p+1)}{t_u \cdot p}\ ; \qquad (19)$$

where $t_u = t_A + t_A^{/}$;

Controller parameters (supply air valve)

$$К_r = К_r \frac{t_A + t_A^{/}}{К_0 \cdot \tau} ; \quad (20)$$

where τ is the parameter control time.

3. Results

The results of calculations and experimental studies of changes in velocity, temperature and gas composition of air supplied to the cowshed along the building's width and length in various sections and in height (Fig. 6, 7, 8, 9) showed that the selected equipment to control primary parameters (air velocity and temperature) ensure microclimate in the cowshed.

Calculations in respective margin conditions are done using Phoenis application software (version 3.5).

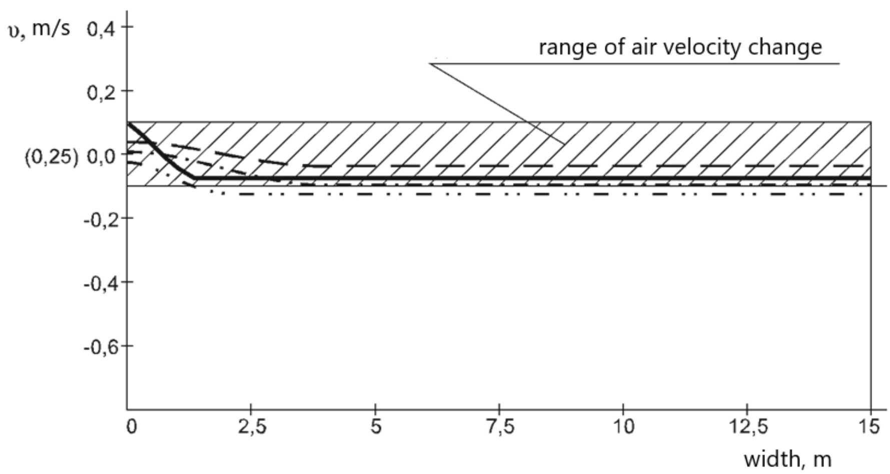


Fig. 6. Change in air velocity in the cowshed along width in various sections (- - - width 5 m, -·-·-·width 10 m, -··-··-·width 15 m). (Compiled by authors)

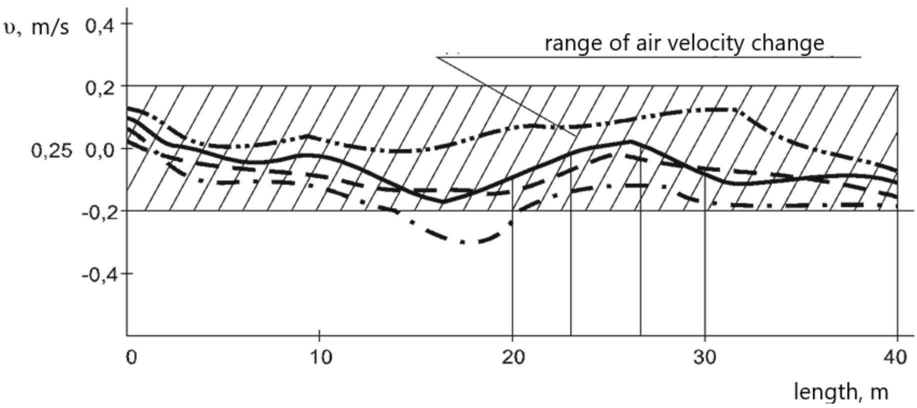


Fig. 7. Change in air velocity in the cowshed along length in various sections (- - - - length 10 m, -·-·-·-length 20 m, -··-··-·-length 30 m). (Compiled by authors)

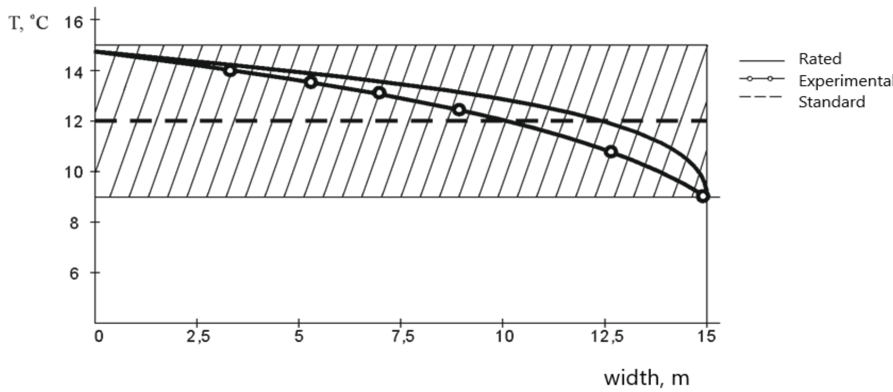


Fig. 8. Changes in air temperature along cowshed width in various sections along height (Compiled by authors)

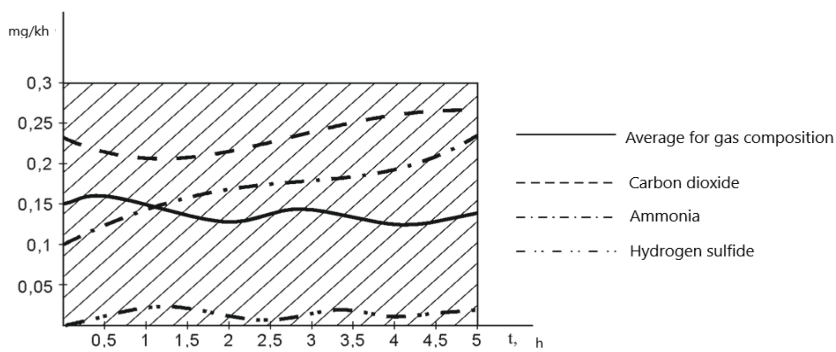


Fig. 9. Changes in air gas composition along cowshed width in various sections along height (Compiled by authors)

The parameters of the inclined part of the manure removal conveyor and some parameters of the biogas unit in case of joint operation have been substantiated. In the existing manure removal conveyor (TSN-160), the inclined conveyor feed when loading manure to a vehicle is 10.92-15.38 kg/s. In this procedure, when the manure is loaded to the biogas unit reactor, it is possible to reduce the inclined conveyor feed depending on the reactor volume. This will reduce the pulling force of required power and conveyor incline angle and substantiate the loading hatch height of the biogas unit reactor.

Taking into account the known design parameters of the conveyor, the dependency has been obtained to calculate the pulling force *P(H)* of conveyor movement:

$$P = 3540,44 \cdot cos\beta + 3439,9 \cdot sin\beta + 2136,02 \quad (21)$$

where β is the conveyor incline angle, deg.

The dependency of the manure delivery height H (design length for a length of 6.52 m) on angle β^0 of conveyor incline (Fig. 10) shows that reasonable heights of the reactor loading hatch are in the zone of $H_{min}^{max} = 2,65...3,\ 25м$. This zone corresponds to the conveyor incline angle $\beta = 25°... 30°$.

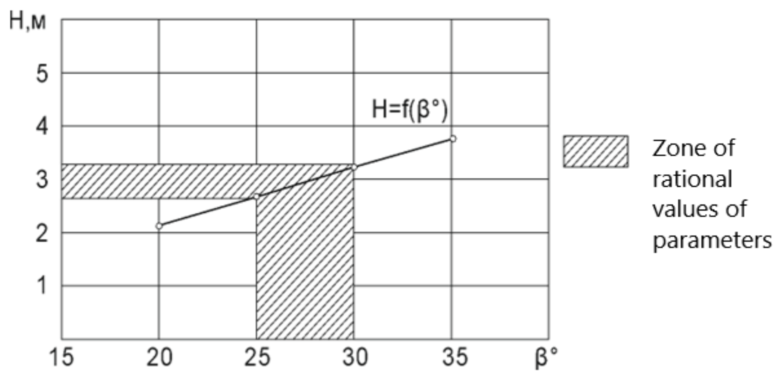


Fig. 10. Dependency of the manure delivery height H on angle β^0 of conveyor incline. (Compiled by authors)

The required power to drive the conveyor's electric motor is calculated using the known formula:

$$N_{mot} = \frac{k \cdot P \cdot \upsilon^r}{102 \cdot \eta_n}; \quad (22)$$

where k is the coefficient taking into account the resistance of tension on the drive sprocket (k=1.1);

υ^r is the conveyor chain speed, m/s;

η_n is the transmission efficiency (% = 0.75 ... 0.85).

For reasonable values of parameters: $\beta=25°...+30°$; $P = 6795,28 ... +6921.99$ N; $\upsilon^G = 0.18$ m/s, power $N_{mot}=15.24 ... 15.53$ kW. For the conveyor chain speed of $\upsilon^G = 0.18$ m/s, the manure supply to the biogas unit reactor is $Q_G^H=2.73 ... 3.84$ kg/s.

The primary indicator to substantiate the reactor volume is the manure weight yield from the cowshed. Moreover, it is required to take into account the temperature conditions of fermentation. In case of thermophilic fermentation, the reactor turnround time is 7.5 days on average.

To calculate the reactor volume, the following formula is recommended:

$$V_r = \frac{M_d \bullet \tau_0 \cdot n}{\rho_n};\qquad(23)$$

where M_d is the daily manure yield from a single animal, kg:
τ_0 is the the reactor turnround time, days;
ρ_n is the manure density, kg/m^3 (ρ_n =1035 kg/m^3);
n is the number of animals.

The recommended volume of the biogas unit reactor for average
$M_d = 35.3 \pm \sigma$ kg $V_p = 38.36$ m^3.

Since the source of heat and electrical energy to heat the cowshed is a biogas unit with a co-generator, the required power of the heater is as follows:

$$P = q \cdot \rho_G \cdot (Q^r_Q \bullet \eta_h);\qquad(24)$$

where q is the required biogas flow rate, m^3/h;
ρ_G is the biogas density (p_g = 1.2 kg/m^3);
Q^r_Q is the low calorific value of biogas (Q^r_Q = 25,000 kJ/kg);
η_h is the heater's efficiency.

This power P is consumed for operation of the electrical heater covering the area of F_h:

$$F_h = \frac{a\left[q \cdot \rho r \cdot (Q^r_Q \bullet \eta_h)\right]}{\Delta t \cdot \kappa};\qquad(25)$$

where a is the reserve coefficient;
κ is the heat transfer coefficient of the electrical heater, kJ/m^{2}h^{0}C;
Δt is the difference of average temperatures, ^{0}C.

For the area F_h, SFO-10 -0,5 –T electrical heater has been chosen, with the capacity of 9.86 kW and 2 heating sections.

For the air flow rate of $Q_A = 9450\text{-}9900$ m^3/h, VCP-5 (C6 -46 No.5) fans has been chosen with the pressure of $H_a = 1900$ Pa, η_h=0.55 and rated capacity of $N_A = 9.06 \ldots 9.5$ kW.

4. Discussion

The development perspectives of livestock management, just as other agricultural branches are related with the use of alternative types of energy based on renewable resources. From this point of view, using the energy of manure as own renewable raw materials with the biogas technology has environmental, social and economic significance. Placing biogas unit in livestock buildings helps processing fresh manure without changing its initial physical-mechanical properties and chemical composition by yielding valuable high-quality products: biogas, biofertilizer, biofuel and heavy water [20], [21].

Biogas as a gaseous fuel with the lower calorific value of $Q^r_Q = 25000$ kJ/kg (

$Q_Q^r = 27000$ kJ/kg for black coal) [22] suggests generation of power [23], [24]. Biofertilizer as an organic fertilizer containing 0.012 g/kg nitrogen, 0.014 g/kg phosphorus and 0.027 g/kg potassium improves soil fertility and water permeability [22].

Autonomous power supply to remote small agricultural farms that are primary producers of agricultural products in the existing structure by anaerobic processing of manure meets the requirements of energy saving since the deficiency of traditional fuel-energy resources grows every year. Moreover, unprofitability of routing centralized power supply lines to remote farms makes it relevant to widely use local renewable sources of energy. Currently, these farms face certain hardships when addressing issues of power supply of production processes and households.

The proposed and tested process scheme of the system for maintaining microclimate in a livestock building by anaerobic processing of husbandry wastes supports autonomous power supply to remote small farms. It excludes such inventive processes as manure charging and transportation to the storage site or in the field, improves unsanitary conditions of the livestock building and around it.

The substantiated parameters of the inclined part of the manure-removal conveyor and the volume of the small bioreactor provide continuous fermentation by means of a controlled manure mass when loading into the bioreactor. This increases the volume of produced biogas and improves the quality of the biofertilizer.

Using automation equipment for control over actuators (valves) in the ventilation-heating equipment helps maintaining primary microclimate parameters within the permitted deviations from standard levels.

5. Conclusion

Modern intensive technologies of livestock management suggest high requirements to microclimate in livestock buildings complying with zoo-hygienic standards which require engineering developments for maintenance and support. A specific feature of livestock buildings is that they have a lot of physical-mechanical and chemical-biological noxious substances that have a negative effect on animals and personnel causing irreversible changes in the body. This results in animal productivity reduction by 30%.

The existing ventilation and heating systems used in livestock buildings are energy-intensive. As an alternative to power these systems, it is suggested to supply power by processing manure using a biogas technology and a co-generator. To accomplish this power supply option, a process scheme has been developed as a new combination and link between the location of process equipment and devices for automatic control over actuators to produce biogas, biofertilizer and electrical energy.

Dynamic models have been developed to select and define the algorithmic structure of this scheme in general as well as individual elements in order to select the automatic control method. A thermodynamic model has been developed in form of *d–h* diagram for a given livestock building that allowed defining a supply zone (warm season) and exhaust zone (cold season). The temperature difference is 3 to -3 ^{0}C from the standard temperature (+12°C), which corresponds to cattle buildings.

Using microclimate automation equipment for cowsheds for 150 animals (milk cows) resulted in: velocity of air supplied to the cowshed that changes along the width in various sections, within 0.1 to -0.1 m/s, along the width within 0.2 to -0.2 m/s at the standard speed (0.25 m/s); the air temperature along the cowshed width in various sections and along height that changes within 3 to -3°C of the standard temperature (12 ^{0}C).

The parameters of the inclined part of the manure-removal conveyor and the volume of the reactor have been substantiated for their joint functioning, e.g., continuous fermentation by batch loading of the required manure mass to the bioreactor. This resulted in: conveyor incline angle 25°to 30°; conveyor chain speed 0.18 m/s; pull force 6795 to 6922 N; motor power consumption 15.24 to 15.43 kW; manure feed by conveyor 2.73 to 3.84 kg/s; bioreactor volume 38.36 м^3; electrical heater required power 9.85 kW; fan required power 9.06 to 9.5 kW; power generated by co-generator 30 to 32 kW.

References

1. Information agency 24kg. Pogolov'e skota v Kyrgyzstane ezhegodno budet uvelichivat'sya na 1-4 procenta. Available: https://24.kg/archive/ru/economics/90548-pogolove-skota-v-kyrgyzstane-ezhegodno-budet.html/
2. R.M. Slavin, Scientific Fundamentals of Production Automation in Husbandry and Poultry Breeding. (Kolos, Moscow, 1987)
3. M.S. Naydelensky, A.F. Kuznetsov, V.V. Khramtsov, P.N. Vinogradov, Zoo-Hygiene with Fundamentals of Designing Livestock Management Facilities. (Kolos, Moscow, 1985)
4. V.M. Yurkov, Microclimate of Animal Farms. (Rosselkhozizdat, Moscow, 1985)
5. Carl Nelson, John Lamb, "Final Report: Haybenschild Farms Anaerobic Digester". (The Minnesota Project, 2002) Available: www.mnproject.org.
6. S.V. Melnikov, Mechanization and Automation of Animal Farms. (Kolos, Leningrad, 1978)
7. V.N. Pismenov, Mechanized Feeding Cattle Farms. (Kolos, Moscow, 1975)
8. M.P. Kalinushkin, Ventilation Units. (Higher School, Moscow, 1967)
9. V.F. Kostyunina, E.I. Tumanova, L.G. Deminik, Zoo-Hygiene with Fundamentals of Veterinary and Sanitary. (Agropromizdat, Moscow, 1991)
10. N.Y. Temirbayeva, System of Energy and Heat Supply of Farms Based on Renewable Resources. (Gazette of Higher Schools, No.6 (057). 40-43, 2012)
11. N.Y. Temirbayeva. Implementation of Biogas Technologies in Kyrgyzstan. (Kazakh National Agriculture University, No.1 (057). 119-122, 2013)
12. Studies of Kyrgyz Market Demand in Biogas Units, (LSA, 2004)
13. Y.J. Osmonov, M.S. Narynbetov, N.Y. Temirbayeva, System for Maintaining Microclimate in Livestock Buildings. (Patent No.167. Kyrgyz Republic. Bull. No.11, 2013)
14. A.A. Rymkevich, Systemic Analysis of Optimization of General Air Ventilation and Conditioning System. (North-West AVOK, 2003)
15. A.Ya. Kreslin, Automatic Control of Air Conditioning Systems. (RII, Riga 1982)
16. A.A. Pervozvansky, Theory of Automatic Control / [A.A. Pervozvansky] (Nauka, Moscow, 1986)
17. V.A. Besekerskiy, E.P. Popov. Theory of Automatic Control Systems. (SPb.: Profession, 2004)
18. A.A. Erofeyev, Theory of Automatic Control. (SPb: Polytechnics, 2001)
19. A.A. Rymkevich, Mathematic (Thermodynamic) Model of Conditioning Systems. (LTIHI, Leningrad, 1979)
20. H. Werner et. al. Economical and Environmental analysis of a biogas plant within a context of a real farm. (The Royal Veterinary and Agricultural University Denmark, 2004)
21. Biomas energy sistems, (ACRE, the Australian CRS for Renewable Energy Ltd) Available: http://www.fluid-biogas.com/?page_id=197
22. V.A. Matveyev, A.B. Tokmoldayev, Determination of Biogas Unit Heat Balance. No.5, 57–59 (Gazette of Agricultural Science. Kazakhstan, 2007)

23. "How small bio-digesters can improve nutrient recycling in agriculture, reduce emissions of greenhouse gases and improve local energy services"? (Prepared for IAC by ETC Energy, 2000)
24. AT information: Biogas, GTZ project information and Advisory Service on Appropriate Technology (ISAT, Eshborn, Deutchland, 1996)