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The use of therapeutic and heat-insulating properties of siliceous gaize in the agricultural sector of the Republic of Kazakhstan

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ABSTRACT

The unsatisfactory environmental situation in the regions of Kazakhstan has a significant impact on the health of farm animals, and livestock products are contaminated with heavy metals such as cadmium, lead, and zinc. Taking into account the ecological state of the environment of the regions, it is necessary to introduce sorbents as feed additives that have a positive effect on the health and quality of meat products. In addition, alimentary diseases associated with the use of poor-quality deficient feed and improper organisation of sanitary measures cause significant economic damage to livestock farming. This explains the relevance of this study. The object of this study is the selection of a natural environmentally friendly raw material and its comprehensive use for obtaining a mineral feed additives and heat-insulating ceramic materials suitable for thermal insulation of the enclosing structures of agricultural buildings. To achieve this goal, gaize rocks of the Taskalinsky deposit in the West Kazakhstan Region are of the greatest interest as a natural, environmentally safe raw material. To determine the local elemental composition of the samples, scanning electron microscopy with energy-dispersive microanalysis was performed. Inductively coupled plasma mass spectrometry was carried out to determine the chemical composition, and mineralogical composition was determined using X-ray diffractometry. Experimental analysis of gaize rocks from the Taskalinsky deposit found that the basis of the mineral part is silicon (Si), which is one of the necessary minerals for the animal body. The mineral part of gaize also contains Na, Mg, Ca, K, and Fe, which are also useful for the animal body. The resulting material can be used as a heat-insulating and structural material for the construction of external and internal walls, for the construction of a warm and chemically resistant floor and as a heater for the roof of agricultural buildings and livestock housing.

Keywords: Animal husbandry, Livestock and Poultry keeping, Mineral additives, Farm animals, Roof insulation

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1. Introduction

Agriculture is the main driver of sustainable development of the economy of Kazakhstan. One of the strategic directions is the development of rural areas and state support of farms engaged in animal husbandry. Therefore, at present, the construction of special agricultural buildings and structures to ensure indoor maintenance of animals at the poultry farms has begun to rapidly develop. In these settings, the organism of livestock and poultry is constantly under the influence of a wide variety of environmental factors.

In terms of importance, these factors can be distinguished in the following order:

1) ecological environment;
2) quality of feed and water;

3) development of new enclosing structures and materials for buildings that provide comfortable conditions in rooms where animals are kept;
4) the pattern of feeding and watering animals;
5) a set of sanitary measures to prevent diseases.

The deteriorating environmental situation in the country has a significant impact on the health of farm animals. Due to pollution of soil, water, and plants, livestock products are contaminated with such heavy metals as cadmium, lead and zinc [1; 2; 3; 4]. Taking into account the ecological state of the environment of the regions, it is necessary to introduce sorbents into the feed of livestock and poultry, which will provide a positive effect on the health and quality of meat products. Significant economic damage to livestock is caused by non-infectious, alimentary diseases due to the use of poor-quality, deficient feed and improper organisation of sanitary measures. As a result, the problem of proper feeding of cattle and poultry and keeping them in environmentally friendly buildings constructed from natural raw materials is of particular relevance. It should be noted that these materials must possess high heat-shielding and construction qualities to provide comfort indoors.

Striving for profitability of production in market conditions, livestock and poultry breeders are forced to use more advanced technologies that ensure the maximum level of health and productivity of livestock [5-10]. At the present stage, one of the progressive ways in achieving the set goals is the use of mineral and biologically active substances in animal feeding. Premixes, mineral and vitamin mixtures play a significant role in this. Analysis of data from foreign and Kazakhstani practice shows that their use in feeding livestock has always been effective [11-20]. However, the purchase of premixes, mineral and vitamin mixtures for animal feeding always requires a significant investment of money. Therefore, it seems promising to use natural sorbents as unconventional feed additives. In this regard, the search for effective, easily assimilated mineral feed additives that compensate for the deficiency of microelements in animal body, ensuring disease prevention is of particular relevance. The optimal therapeutic measures are products of mineral and biological origin from the area where the growth and development of the animal takes place.

In recent years, interest in the use of alternative local mineral resources in the general feed balance has increased. Significant positive experimental data have been accumulated on the use of zeolite-containing tuffs of the volcanic and volcanic-sedimentary type (with a zeolite content of 50-60% or more) as a mineral additive in the diets of livestock and poultry [21-28]. The effect of zeolites is manifested primarily in the gastrointestinal tract. It is due to the buffering, ion-exchange, and sorption properties. There are positive results of using siliciferous marls as a mineral supplement for a dairy herd, young cattle, poultry, fur-bearing animals.

In parallel with solving the problem of rational animal feeding, it is necessary to solve the problem of creating comfortable conditions for their keeping. One of the important factors in preserving the health and productivity of animals is the creation of the required microclimate inside the premises where animals are kept. The results of many years of research indicate that the wrong choice of building materials for the construction of external walls and flooring and other structural solutions for agricultural buildings also negatively affects the health and productivity of animals. In such a situation, the temperature and humidity conditions, as well as normal air exchange, are violated inside the room. It has been proven that the ambient air temperature significantly affects the metabolism in the body of animals. Not only the health of animals depends on this, but also their productivity. If the air temperature is low, then the metabolism in the body of animals increases, heat production increases, as a result of which the animals require additional feed. To avoid an increase in feed costs and maintain a favourable microclimate, it is necessary to create an optimal temperature regime in livestock housing. A favourable air temperature is considered to be +10 – +15 °C. For example, if a cow is kept at temperatures below +5 °C, then there is a decrease in milk yield from each cow by 1-2 litres, which leads to an increase in production costs. This means that it is very important to ensure good and high-quality insulation of the barn.

The object of this study is the selection of a natural, ecologically clean raw material and its comprehensive use to obtain a mineral feed additive and heat-insulating ceramic material, suitable for thermal insulation of the enclosing structures of agricultural buildings [29-36].

2. Materials and methods

To achieve this goal, the gaize of the West Kazakhstan Region are of the greatest interest as a natural ecologically clean raw material. Gauze mined in the West Kazakhstan is a light, solid, microporous rock

(Figure 1). The siliceous deposit has a colloidal microgranular structure and opal-chalcedony composition. According to geological data, gaize is deposited in Paleogene and Cretaceous sediments and are formed in sea basins due to the compaction and cementation of diatomites and tripoli. Their density is 1.3-1.5 g/cm^3. White or gray, greenish light rocks with rare remnants of diatoms, radiolarians, and sponge spicules.

Figure 1. Gaize – siliceous rock of the West Kazakhstan deposit in its natural form

To create a favourable temperature regime in winter, it is necessary to calculate the thermal insulation of buildings. The heat output of cows in the barn at +10 °C should exceed the heat loss of the structure. And since animals need an influx of fresh air, it is necessary to take into account the heat loss caused by the operation of the ventilation system. And if the room is ventilated less often, then the level of ammonia vapours in the air in the barn will increase. The formation of toxic ammonia fumes causes poor health in cows, a decrease in their appetite and productivity. The wrong choice of materials for thermal insulation of walls, floors, and roofs of agricultural buildings for keeping animals leads to the condensate formation on internal surfaces. As a result, the room creates favourable conditions for the reproduction of various pathogenic bacteria. Therefore, there is an objective need for further scientific investigation to improve the composition of feed and create new types of heat-insulating materials to improve the conditions for animal housing [37-42].

When selecting a raw material, it is necessary to consider their versatility. In short, one raw material should serve as a mineral feed additive and a heat-insulating material for the enclosing structures of livestock buildings. As one of the promising ways to solve this problem, it is proposed to use siliceous opal-cristobalite rocks – gaizes and their varieties – gaize-like clays, which are widespread in many regions of Kazakhstan. The use of this type of raw material for the production of heat-insulating ceramic materials is of great interest due to their chemical and mineralogical composition, providing unique properties such as lightness, high porosity, thermal insulation and the ability to sinter during heat treatment [43-55]. The future belongs to ceramic materials with a porous structure (porosity up to 62-68%), with a density of 700-800 kg/m^3 and increased heat-shielding properties (thermal conductivity less than 0.2 W/m°C). In developed countries, the share of such ceramic materials is up to 50-80% of the total volume of manufactured products [56-67]. Studies of the chemical and mineralogical composition of siliceous rock – the gaize of the Taskalinsky deposit in the West Kazakhstan Region (Figures 2, 3).

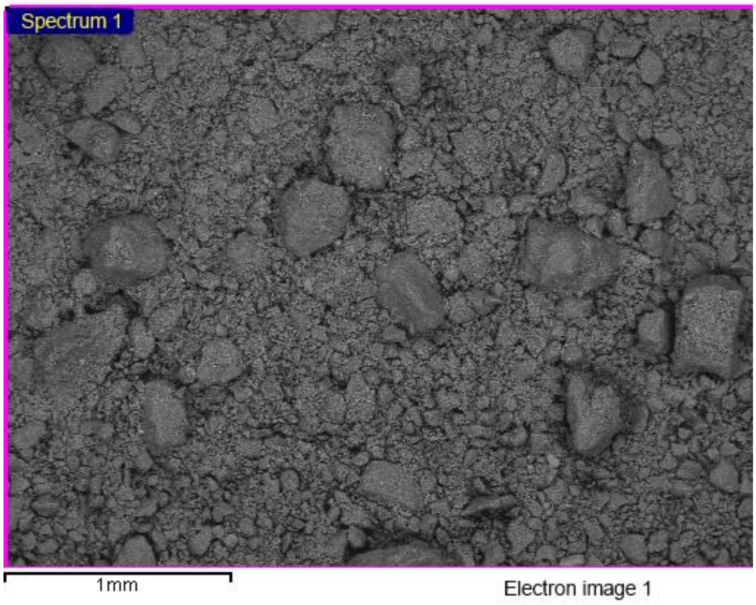

Figure 2. The microstructure of the gaize of the Taskalinsky deposit

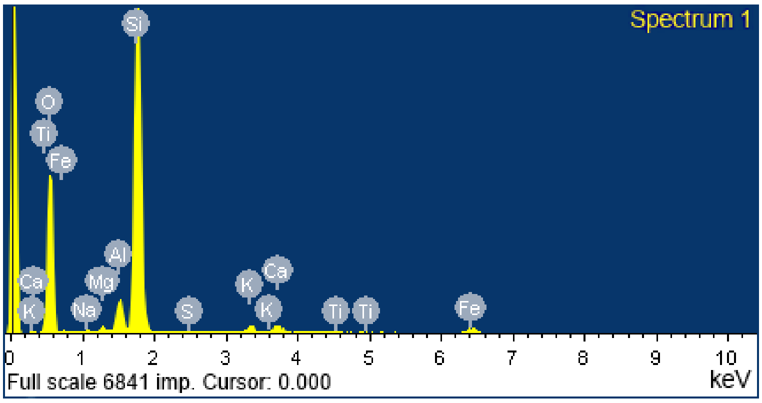

Figure 3. Spectrum of siliceous rock in the gaize of the Taskalinsky deposit

The reserves of gaize are more than 4570 thousand m^3. The useful stratum is represented by thin-layered porous rock of light grey colour from the Lower Paleogene sediments. The thickness of the useful strata is 4.25-28.0 m, the average is 19.1 m. The study used the following modern analytical equipment of the regional engineering laboratories of Auezov South Kazakhstan State University: scanning electron microscope JSM-6390LV with a system of energy-dispersive microanalysis; X-ray diffractometer X'Pert PRO MPD; inductively coupled plasma mass spectrometer ICP-MS Agilent 7500cx. To determine the local elemental composition of the samples, scanning electron microscopy with energy-dispersive microanalysis was performed. Inductively coupled plasma mass spectrometry was carried out to determine the chemical composition, and mineralogical composition was determined using X-ray diffractometry.

3. Results and discussion

One of the common raw materials promising for the use as a mineral component in the creation of biomineral active substances are siliceous-carbonate rocks with high sorption properties and elements useful for the animal body. These siliceous rocks are sedimentary deposits distinguished by the presence of well-preserved remains of flora and fauna, consisting of biogenic silica (radiolaria and diatoms) [68; 75]. In addition, gaizes are capable of forming a ceramic shard with high porosity and low thermal conductivity [76-81]. Therefore, scientific and experimental studies were carried out in two directions: the use of gaize as a mineral feed additive and an adsorbent for birds; the use of gaize as the main raw material for obtaining a porous ceramic material with low thermal conductivity [82-124].

The studies showed that the bulk of the opal mass of the rock is literally "saturated" with clay substance. The clay component is present in the amount of 20-50%. There are individual organogenic remains in the form of sponge spicules. Silty material is represented mainly by quartz grains (up to 15%) and glauconite grains (about 5%) of bright green colour. Relatively large (up to 0.5 mm) mica flakes are quite often observed. The concentration of iron hydroxides is clearly visible along the microcracks. Analysis of the gaize sample made it possible to assert that the sample has an amorphous structure. The spectrum of X-ray diffraction patterns clearly shows the prevalence of quartz – SiO_2. Opal is represented by a structureless and microglobular mass, in places it turns into chalcedony. There is an admixture of clay, sandy grains of quartz, feldspars, mica, glauconite (Table 1). The sorption properties of gaizes were determined using the Sorbtometer-M device at the Tambov State Technical University.

Table 1. Chemical elemental composition of the gaize of the Taskalinsky deposit

Element	Weight %	Atomic %
O	53.68	67.97
Na	0.21	0.18
Mg	0.55	0.46
Al	3.40	2.55
Si	36.53	26.35
S	0.19	0.12
K	1.18	0.61
Ca	1.33	0.67
Ti	0.18	0.08
Fe	2.75	1.00

Due to the smallest constituent particles, gaize has a huge adsorption surface. According to the research data, the sorption capacity of the gaize was within 800-850, m^2/g. Natural sorbents as gaize contain a large amount of biogenic macro-, micro-, and ultra-microelements, which can actively participate in a wide variety of metabolic processes and correct the biochemical and antigenic-structural homeostasis of animals.

The first series of experiments was carried out on 320-day old laying hens on the basis of scientific laboratories of the "Shamshyrak" agricultural production cooperative (APC) in the city of Uralsk, West Kazakhstan Region. In the first (experimental) and second (control) groups, the number of birds at the beginning of the experiment was 300. A production test of the effectiveness of the gaize as an adsorbent of toxins was carried out with mixed chronic mycotoxicosis of birds. During mycotoxicological studies of 4 samples of compound feed, molds of the Fusarium, Mucor, Aspergillus genera were isolated. A test on Stylonychia showed low toxicity of feed. The following mycotoxins were identified by enzyme-linked immunosorbent assay using ELISA-OEP device: T2 at a concentration of 93±5 μg/kg and ochratoxin A at a concentration of 11±3 μg/kg.

The average egg production of birds was 71.4%, survival rate was 85.4%. In bacteriological studies of pathological material, pathogens of infectious diseases have not been isolated. The main causes of mortality were non-infectious diseases: hepatitis, enteritis, cloacitis. In a sick bird, clinical signs were manifested by despondency, comb and jowl cyanosis, and refusal to feed. Defecation was impaired, the skin around the cloaca was inflamed, hyperemic, edematous, and contaminated with feces. The experiments were carried out for 90 days. Experimental group of birds No. 1 was fed with the gaize supplement in ten-day cycles with two-stage mixing with fractions of 1-2 mm in a mixture with compound feed in amount of 2% of the mass of feed. Control group No. 2 received feed of the main ration used on the farm. Throughout the experiment, a daily clinical examination of the laying hens was carried out, the productivity and safety were recorded, the feed conversion was assessed, and a postmortem examination of the dead bird was carried out to establish and clarify the diagnosis. The results of the experiment are presented in the Table 2.

Table 2. The efficiency of using gaize as an adsorbent of toxins in poultry farming (M±t; p=10690)

Groups	Animal units	Egg production rate, %	Dead	
			animals	%
Experimental group No. 1	300	86.4%	18*	7.0
Control group No. 2	300	76.5%	33	11.0

*Note: * – degree of confidence P <0.05*

From the data in the table, it can be seen that during the experiment, egg production in the experimental group increased by 9.9%. The difference in mortality between the groups was 4.0%. In addition, the average weight of one egg of the hens in the experimental group by the end of the experiment was 3.8 g more (51.7 g versus 47.9 g in the control).

In the course of the study, it was found that the inclusion of an adsorbent in the form of gaize in the diets of laying hens leads to an increase in the quality of the shell and an increase in the mass of eggs. It should be noted that feeding the adsorbent, the active component of which is gaize, enhances the sorption of calcium from the feed due to an excess negative charge on the surface of the latter, followed by re-adsorption of this macroelement in the gastrointestinal tract, which, in turn, leads to an improvement in the quality of the shell, reduction of notches and breakage.

In the experimental group, the eggs obtained from the hens were distinguished by their greater strength. Thus, gaize, used as an active base of the adsorbent, due to the peculiarities of its crystal structure, has a high sorption activity, which allows it to effectively bind and remove toxic substances from the body, and first of all, toxins of microbial cells and mycotoxins. Largely due to all of the above properties of the gaize, the use as an adsorbing agent when feeding mixed fodder affected by mould fungi and their metabolites, in doses from 0.5 to 2% of diet in dry matter, relieves symptoms of toxicosis. In addition, it has a positive effect on the physiological state, safety and productivity of animals, and also improves feed intake.

To carry out experimental efforts in the other direction, the gaize was first dried in a drying cabinet and subjected to preliminary crushing using a laboratory jaw crusher. Then gaize was ground in a laboratory ball mill until it passed through No. 1.0. The composition of the raw mixture was selected with the following limiting concentrations of components, wt.%: gaize 70-80, clay 17-25, coal 3-5 (Table 3).

Table 3. The studied compositions of ceramic masses based on gaize

No. of composition	Name and content of raw materials, wt.%		
	gaize	clay	coal
1	70	25	5
2	75	21	4
3	80	17	3

By weighing, the raw materials were dosed according to the test compositions and loaded into a laboratory ball mill for joint grinding to obtain a homogeneous powder mixture. The resulting mixture was fed into a laboratory mixer and water was added and thoroughly mixed again until a plastic ceramic mass was obtained. The moulding moisture content of the ceramic mass was 25-27% by weight of dry components. Samples of cylinders with dimensions of 50x50x50 mm were moulded from the ceramic mass by the soft-mud process. The resulting cylinder samples were dried in a drying oven to a residual moisture content of 8-10%. General appearance of raw cylindrical samples is shown in the Figure 4.

Figure 4. Laboratory raw cylindrical samples

The obtained cylindrical samples were fired at a temperature of 1000 °C in a laboratory muffle furnace with a temperature elevation rate of 150 °C per hour. The samples were soaked at the final temperature for 1 hour, and then left with the oven turned off to room temperature. Heat-treated ceramic cylindrical samples were subjected to physical and mechanical tests according to the rules of standard procedures. The most important physical and mechanical properties of the sample were chosen as the studied properties, characterising their efficiency as average density, g/cm^3, compression resistance, MPa, water absorption, %, total porosity, % thermal conductivity, W/(m°C), and chemical resistance to 10% hydrochloric acid (HCl). General appearance of heat-treated cylindrical samples at a firing temperature of 1000 °C is presented in the Figure 5.

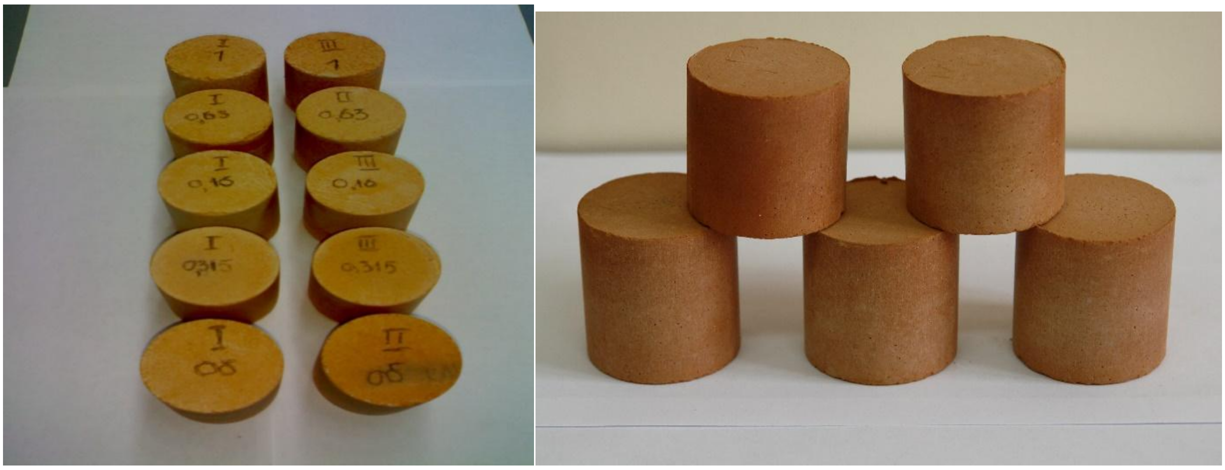

Figure 5. Laboratory cylindrical samples heat-treated at a temperature of 1000 °C

For a comparative analysis of the results of experimental work, control samples based on ceramic masses of pure loam were moulded in parallel. The results are presented in the Table 4.

Table 4. Physical and mechanical properties of ceramic samples heat-treated at a temperature of 1000 °C

No. of composition	Average density, g/cm^3	Compressive resistance, MPa	Water absorption,%	Total porosity,%	Thermal conductivity, W/(m°C)	Chemical resistance to 10% HCl
1	0.62	12.4	33	57	0.21	96.3
2	0.67	11.9	32	54	0.23	97.5
3	0.71	10.7	31	52	0.27	98.4
Loam control samples	1.85	7.5	25	22	0.7	80.4

As a result of the analysis of the physical and mechanical properties of heat-treated samples at temperatures of 1000 °C, it was possible to establish the basic laws of their change depending on the component composition of the raw material system. Comparative analysis of changes in the physical and mechanical properties of samples of the studied compositions of ceramic masses in comparison with ceramic samples based on loam showed significant changes in all properties. Specimens based on the investigated ceramic mass have a lower average density, higher chemical resistance, and total porosity increased more than 2 times. In addition, they have a reduced coefficient of thermal conductivity (0.21-0.27 W/m°C versus 0.7-0.8 W/m°C), which is one of the important criteria for the energy efficiency of the material. In addition, despite the high values of total porosity, the samples have high compressive strength (10.7-12.4 MPa versus 7.05 MPa).
To study the morphology of the porous structure of the studied ceramic cylinders, the samples were cut using a cutting tool (Figure 6). On the basis of visual inspection and examination under a microscope, it can be stated that the samples are a strongly sintered ceramic material of light red colour with a macro- and microporous structure. Macro- and micropores are evenly distributed throughout the volume.

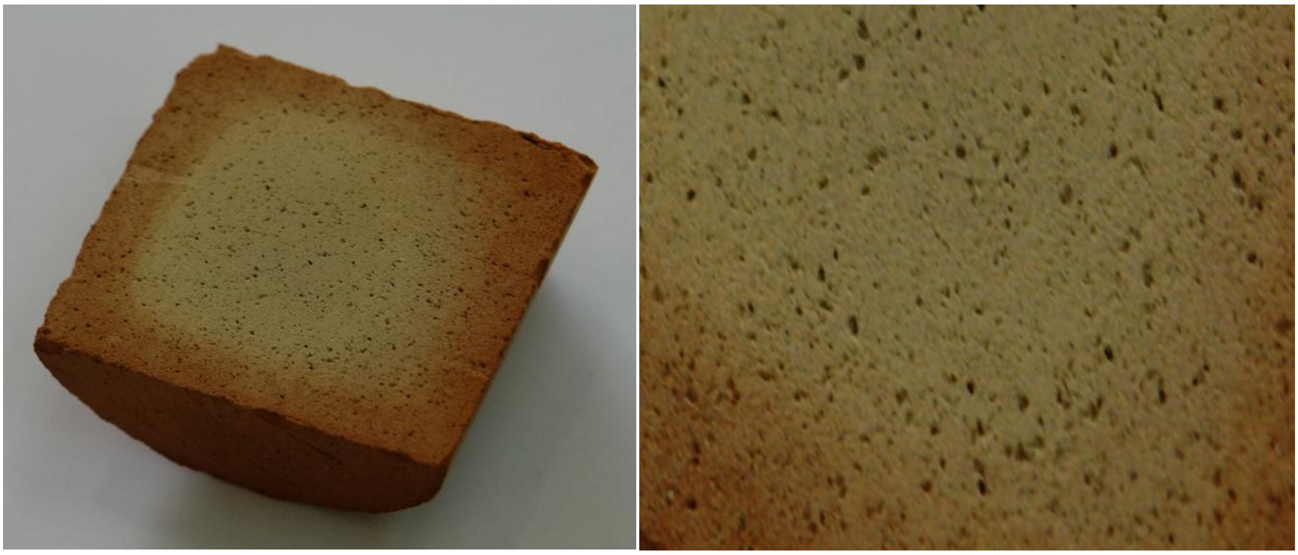

Figure 6. The porous macrostructure (in the cut) of heat-treated cylindrical samples at a temperature 1000°C

The changes occurring in the physical and mechanical properties in the studied ceramic masses are associated, first of all, with the chemical and mineralogical characteristics of the raw materials used. A decisive role in the establishment of a porous structure and low average density and thermal conductivity is played by siliceous rock – gaize and coal. By nature, it has high porosity and low average density. Clay acts as a binder for two non-plastic materials in the shaping stages and the solid-phase and liquid-phase sintering at the firing stage. As a result, a sintered solid crystalline phase with a fine-pored structure is formed, which explains the high strength characteristics of the samples, despite the high total porosity. Thus, on the basis of the investigated compositions of ceramic masses, it is possible to obtain effective ceramic materials differing in lightness, required strength, high chemical resistance, high total porosity, and low values of the thermal conductivity coefficient.
The results of studies of the second direction show that the obtained material can be used as a heat-insulating and structural material for the construction of external and internal walls, a warm and chemically resistant floor and as a heater for the roof of agricultural buildings and livestock housing. The considered material meets the number of important criteria:

- fire safety, as the ceramic material based on the gaize is not combustible;
- ecological safety, since the composition of material is completely free of substances that can harm the health of animals;
- vapour resistance, which prevents condensation that can worsen indoor climate and cause active rotting of feed and bedding;
- eliminates the destructive effect of condensation on the structure of an agricultural building;
- mechanical strength, in case of accidental impacts the material does not collapse or fracture;
- chemical resistance of the material excludes decay of the building from the effects of chemical factors.

4. Conclusion

Based on the findings of scientific, experimental, and empirical research, the most important factors affecting the health and productivity of animals and birds have been identified. In terms of influence, these factors can be distinguished in the following order:
1) ecological environment;
2) quality of feed and water;
3) development of new enclosing structures and materials for buildings that provide comfortable conditions in rooms where animals are kept;
4) the pattern of feeding and watering animals;
5) a set of sanitary measures to prevent diseases.

The studies of chemical and mineralogical composition, the structural and biological characteristics of gaize of the Taskalinsky deposit revealed the following special properties:

- the basis of the mineral part of gaize is silicon (Si), which is one of the essential minerals for the animal organism;
- the composition of the mineral part of the gaize also contains Na, Mg, Ca, K, Fe, which are also useful for animals;
- high sorption capacity of the considered mineral predetermines the possibility of its use as a sorbent for cleaning the animal body from toxins;
- physical and mechanical properties of gaize provide the creation of effective heat-insulating ceramic materials that are lightweight, durable, with high chemical resistance, porous structure, and low heat conductivity.

The study shows that the obtained material can be used as a heat-insulating and structural material for the construction of external and internal walls, a warm and chemically resistant floor, and as a heater for the roof of agricultural buildings and livestock housing.

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