Manure as a source of energy and heat-insulating material in the cold climate of Yakutia

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Abstract. Energy is essential for the development of human society. Biogas plants, as a part of an integrated product-to-energy system, are an alternative to the use of waste biomass as raw materials due to their energy production capacity and thermal insulation material. Animal waste is an important resource that is used to replenish organic matter and improve soil conditions. Depending on the weight, cattle produce approximately 4 to 6 tons of fresh manure per year. With the constantly increasing prices for fossil energy resources, as well as the depletion of oil and gas reserves, an increasing number of countries are developing alternative energy sources. One of these types is biogas. It is necessary to note that the main disadvantage of biogas energy is the significant weight of specific capital costs and low profitability of projects. Despite this, in Russia there is the increase in demand for biogas units (BGG), both for small consumers (with a digester volume of 3-20 m³) and for medium-sized consumers (with a digester volume of 30-100 m³). The point is that biogas technologies properly fit into the UN Doctrine of sustainable development of society. Many in Russia are committed to this idea. They are guided by the principle “Reason is a clumsy instrument of a scientist; intuition is the unmistakable leader of the seer” and try to solve this problem each in his own way. According to UN experts, this very integrated approach, when a scheme for the selection of enterprises and industries operating on one type of raw material is carried out, and waste and by-products of one production act as raw materials or semi-finished products for another type, can completely solve the problem of sustainable development of society.

1. Introduction
It is known that animals do not fully assimilate the energy of plant feed and more than half of it goes into manure, which is a valuable organic fertilizer and, after processing at BGU, the effluent can be used as an environmentally friendly heat-insulating material. Therefore, it is necessary to introduce an acceptable version of biogas plant. In the cold climate of the Republic of Sakha (Yakutia), the resulting effluent gives an environmentally friendly heat-insulating material and alternative fuel instead of expensive hydrocarbon fuel.

Research purpose is to describe the study of the use of biogas power plants and the state and preconditions of biogas energy; to study the use of local heat-insulating material for residential buildings in cold climates and the possibility of using natural heat from the feed shop to heat the biogas plant components at low temperatures and the use of processed raw materials (effluent).

2. Results and discussion
Biogas is the general name for a combustible mixture obtained from the decomposition of organic substances as a result of an anaerobic microbiological process. For the efficient production of biogas from organic raw
materials, comfortable conditions are created for the vital activity of several types of bacteria in the absence of oxygen [1, 2]. The energy value of biogas is 60-70% of the energy value of natural gas.

Table 1. State and prerequisites for the growth of biogas energy in the Russian Federation (billion m³)

|          | 2015 | 2020 | 2025 | 2030 |
|----------|------|------|------|------|
| Biogas volume | 300  | 500  | 610  | 900  |

Biogas yield from the main raw material per year:
- One head of cattle gives a year: $300 \div 500$ m³;
- One hectare of meadow grass: $6000 \div 8000$ m³;
- One hectare of fodder beet: $8000 \div 12000$ m³;
- 10,000 poultry: $12000$ m³;

Depending on the type of organic raw materials, the composition of biogas can vary, but in general, it includes: methane (CH₄), carbon dioxide (CO₂), small amounts of hydrogen sulfide, ammonia and hydrogen (H₂S; NH₃, H₂).

Table 2. Description of the composition of biogas obtained from the biogas plant

| Composition  | Specific heat of combustion | 1 m³ biogas is equivalent to 1 l of diesel fuel |
|--------------|-----------------------------|-----------------------------------------------|
| Biogas       | 2/3 of methane (combustible gas) | $60 \div 70\%$ of natural gas                  | $2.8 \div 4.1$ kW of heat                      |

Modern energy problems can be solved only with the rational use of all existing sources of fuel and energy. For example, biomass, as a constantly renewable source of fuel, occupies an essential place. The technology of the production of biogas and processing organic waste into high-quality fertilizer by means of anaerobic digestion is successfully used in a number of countries. The first biogas plants for biogas production appeared in countries with a warm climate, since the amount of gas produced largely depends on the temperature: the higher, the greater the rate and degree of fermentation of organic raw materials. The construction of a biogas plant is relevant for both newly created farms and old ones [3, 5].

In modern times, there are problems of building a biogas plant in rural areas with a cold climate. Each company is individual, therefore, in each case the financial costs must be calculated by specialists. Wastewater treatment plants consume about 50% of energy, and during the construction of a biogas plant, 50% savings occur. The project pays off by the reduction of the cost of production, since the costs of buying gas, electricity, hot water and the sale of fertilizers are reduced. In a cold climate and based on the volume of production in the Republic of Sakha (Yakutia), we propose to take the size of the site under the biogas plant taking into account the volume of the feed room of the farm.

The studies show that heat losses through individual elements of the enclosing structures of large-block and panel buildings are far from equivalent:

- 30-40% of the total heat loss of buildings in the North falls on the outer walls, 45-50% on the windows, the area of which is 15-17% of the total area of the outer fences. Therefore, among the measures aimed to reduce heat consumption for heating, it is necessary to pay special attention to the increase in the resistance to heat transfer of external fences through the use of high-performance heaters and heat-shielding glasses in window openings.

The reduction of the cost of rural construction can be facilitated by the effective use of building materials from local raw materials using energy-saving technologies, which include unfired brick, soil concrete and foam concrete. In the conditions of Yakutia, in order to study and evaluate the operational efficiency of the most energy-saving building materials from clay and sandy soils in the climatic conditions of the North, the experimental dwelling houses were built on the territory of the Republic of Sakha (Yakutia): in the village Borogontsy of the Ust-Aldan region, in Yakutsk and in the village Maya Megino in the Kangalassky region. In a frame building built in the village Borogontsy, frame struts made of thin gauge, by means of straps and
purlins, were combined into a rigid spatial system, which ensured the overall stability of the building and took up loads.

Thus, the overall stability of the building is ensured by the joint work of the outer walls, the hard disk of the covering (combined roof) and the preservation of the permafrost state of the soils for the entire period of construction and operation. The walls were coated with clay sawmill in two steps. The first layer was thrown over the structure of the walls from the outside and inside, thus that the mass penetrated between the wooden stakes and filled the space between them. In this case, the surface of the applied clay mass is not leveled. The second layer is applied after drying the previous one. The results of the external tests carried out in the first year of operation of a residential building in the village of Borogontsy showed some deviation of the actual parameters from the calculated values:

- the average temperature level in the residential premises of the building was 23°C, which fully met the requirements of thermal engineering standards, however, temperature fluctuations reached 10-12°C, which was much higher than the permissible;
- the air temperature at the floor was 14.5-16.8°C, and the temperature drop at a height of 1.5 m was 3.2-3.9°C, which exceeded the standard difference by 2°C. However, in comparison with houses with ventilated undergrounds, the temperature mode of the floors in this building can be characterized as quite satisfactory;

One of the traditional industries in the rural areas of the Republic of Sakha (Yakutia) is the breeding of cattle. A distinctive feature of keeping livestock in the north is a long (about 240 days) stall period. During the winter, a lot of manure is collected, which is formed into briquettes and stored until warm days. According to the statistics agencies, as of January 1, 2020, 190 thousand heads of cattle are kept at enterprises of all forms of ownership of the Republic of Sakha (Yakutia). The output of manure from one head in the north is 5 kg per day. Accordingly, from one head for the entire stall period, according to approximate calculations, 1.2 tons of manure are obtained and 470 thousand tons of manure for all livestock.

This amount of manure needs to be used not only in the form of compost and humus, but we also suggest using it as insulation as an available local material. For this purpose, we conducted the experiment in order to compare the thermal insulation properties of some materials.

For the experiment, in a box 2.5 cm thick, 17 cm wide, 25 cm long, 12 cm high on a snow packed platform the following were brought in: fresh frozen manure, manure dried in natural conditions, biogas plant substrate, chipboard, polystyrene, penofol, packed snow. The experiment was carried out at an outside air temperature of 35°C below zero. We took 1-liter vessels with water at a temperature of 30°C above zero and placed them inside each box. During the day, starting from the setting at 8:30 am, the measurements were taken from 9:30 am and every subsequent hour until 5:30 pm. At noon, the outside temperature was 21°C. The results of the experiment are shown below.

Table 3. Characterization of thermal insulation materials based on the experiment

| Time  | Biogas Substrate | Dry component | Polystyrene | Packed snow |
|-------|------------------|---------------|-------------|-------------|
| 9:30  | 30°C             | 30°C          | 30°C        | 30°C        |
| 10:30 | 17°C             | 14°C          | 13°C        | 9°C         |
| 11:30 | 13°C             | 10°C          | 9°C         | 6°C         |
| 12:30 | 10°C             | 7°C           | 6°C         | 3°C         |
| 13:30 | 7°C              | 4°C           | 4°C         | 1°C         |
| 14:30 | 5°C              | 2°C           | 2°C         | 0°C         |
| 15:30 | 3°C              | 1°C           | 0°C         |             |
| 16:30 | 2°C              | 0°C           |             |             |
| 17:30 | 0°C              |               |             |             |

According to the data in the table, the biogas substrate has the best technical characteristics. The potential risk of heavy metals for crops is caused by several factors, including the nature of the heavy metals, soil
cation exchange properties, nutrient status, organic matter content, redox potential, plant species, agronomic conditions, etc. [2, 5].

**Table 4.** The results of a laboratory study of effluent substrate of biogas plant for heavy metals

| №   | Research indicator                  | Research dataset | Value of parameters | Actual result |
|-----|------------------------------------|------------------|--------------------|---------------|
|     |                                    |                  | Approximate permissible concentration in soil |                |
| Toxicological indicators: |                                    |                  |                    |               |
| 1   | Lead, mg / kg, no more             | GOST 30178-96    | 32.0-130.0         | 0.47 ± 0.061  |
| 2   | Cadmium, mg / kg, no more          | GOST 30178-96    | 0.5-2.0            | 0.18 ± 0.0155 |
| 3   | Mercury, mg / kg                   | GOST 26927-86    | 2.1                | 0.0068 ± 0.0009 |
| 4   | Arsenic, mg / kg                   | GOST 26930-86    | 2.0                | 0.0086 ± 0.0006 |
| Radiological indicators | Cesium-137, no more | IU, 2004 | 370.0 | 3.0 ± 7.5 |

For the operation of a biogas plant (unit), the following components and devices are required:
- the preparation of raw materials;
- the production of biogas and fertilizers;
- the purification and storage of biogas;
- the production of electricity and heat;
- automated control system of BGU.

The BGU digester should be hermetically sealed. There should be no access to oxygen (because only in the absence of oxygen, the vital activity of methane-forming bacteria is possible) [1, 2, 5].

The optimal temperature of methanogenesis depends on the type of substrate (organic waste) processed by the unit. Control and measuring devices installed on the digester should ensure control of the substrate level in the digester, temperature and pressure inside it. In the digester, it is necessary to organize periodic mixing of the substrate, which ensures the efficient and stable operation of the biogas plant. The purpose of mixing is to release the generated biogas, mix the fresh substrate and bacteria (grafting), prevent the formation of crust and sediment, prevent the formation of areas of different temperatures inside the digester, provide even distribution of the bacterial population and prevent the formation of voids and accumulations that reduce the effective area of the digester.

During the choice of a mixing method, it is necessary to take into account that the fermentation process is a process of vital activity of symbiosis of various bacterial strains and if this community is destroyed, the fermentation process will be unproductive until a new community of bacteria is formed [1]. Therefore, too frequent or prolonged stirring is harmful. Slow mixing of substrate is recommended every 4-6 hours. Optimal mixing of raw materials increases the biogas yield up to 50%. Biogas plants provide utilization (processing) of organic waste of 3 and 4 hazard classes (according to the Decree of the Government of the Russian Federation of 12.06.2003, No. 344) in the following modes:
- in a psychrophilic mode - with an optimal temperature in the digester of 15-20 °C (maybe even lower). In this mode, waste is processed for 30-40 days. The psychrophilic mode is usually used in the summer season when the heat and the amount of substrate (waste) is much less than usual, for example, due to grazing;
- in mesophilic mode - at a temperature of 30-40 °C, when organic waste is processed for 7-15 days, depending on the type of waste;
- in thermophilic mode - at a temperature of 52-56 °C, when organic waste is processed in 5-10 days, while the quality of gas and fertilizers is usually lower than in the mesophilic mode for a number of indicators. In addition, in thermophilic mode, more energy is traditionally consumed for heating. This mode
is most suitable for those whose main task is to recycle a large amount of waste. Optimizing the operation of the plant and the composition of the waste, it is possible to speed up the processing up to 3-4 days. The benefit of the operation in a thermophilic mode is that the cost of 1 kW of the installed capacity of the biogas plant is sharply reduced. We designed a biogas plant with heating from the feed shop. The energy of the feed shop of a farm (the floor of the feed shop, covering the bottom side surface of the digester) can be used for heating the substrate and for biogas plant (Fig. 1).

![Figure 1](image_url)

**Figure 1.** Diagram of a small digester with heat transfer from the feed shop: 1 – digester, 2 – substrate, 3 – feed shop equipment, 4 – direct heat transfer, 5 – feed shop, 6-6 - gasproof insulation

Digester 1 is located under the feed shop 5, which receives direct heat transfer from the equipment of feed shop 3 and reflected from the lateral outer surface of the digester 1. For safety, a gasproof layer is installed between the feed shop and the digester. Maintaining the required temperature of fermentation in the digester 1, due to the use of thermal energy (heat of the brine) is ensured as follows.

Further maintenance of the temperature of the substrate within the required limits can be ensured both by synchronous regulation of the supply of hot raw materials and removal of the effluent, and by filling the gaps with water periodically and creating a low vacuum in these gaps. Such a combined installation for biogas production can ensure the operation of the digester 1 in a thermophilic mode, including in early spring and late autumn, with the costs of the produced biogas for its own technological needs.

In the conditions of the Republic of Sakha (Yakutia), it will be difficult to produce biogas at such a biogas plant in winter because of cold climate, but the use of feed shops is now extremely important due to drought. Therefore, due to the lack of roughage, it is necessary to organize feed shops and to reduce costs. We propose to solve the problems of the lack of feed and the use of manure by the construction of feed shops together with biogas units. The diagram of a digester with heating from the equipment of the feed shop shown in Figure 1 is suitable for both small and medium biogas plants.

3. **Conclusion**

The costs of a biogas plant with heating from the equipment of the feed shop are significantly lower than the cost of a traditional biogas plant with the same volumes of digesters. At the same time, the use of a thermophilic fermentation mode additionally leads to the decrease in the cost of 1 kW of their installed power. During the spring and autumn period of the operation of a biogas plant with an SSP, when operating most of the time in a thermophilic mode, more commercial biogas and effluent can be produced in comparison with a traditional biogas plant. The use of heat energy by the equipment of the feed shop seems to be promising for heating and maintaining the temperature of fermentation of the substrate in digesters in optimal volumes in cold climate. According to the results of the laboratory experiment of the effluent and on the calculations of thermal conductivity as a heat-insulating material, we propose to use this environmentally friendly material with appropriate heat-insulating properties in the conditions of the North.
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