Biogas technologies in the heat and gas supply systems for the agricultural organizations in the Saratov region

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Abstract. One of the advantages of using biogas plants is the biogas production to generate thermal energy. The useful consumption of generated energy depends on the biogas plant’s thermal protection optimization level. The purpose of the study is to search for technical solutions and justification of optimal parameters for increasing the energy efficiency of a biogas plant used in the thermal energy generation to create a favorable microclimate in livestock buildings. The design and technological features of a biogas plant depend on the process stages, the shape of the reactor, and the types of mixing. The criteria for energy efficiency are the lowest cost of energy consumed by a biogas plant for its own needs. A comparison of the insulating materials’ energy indicators made it possible to establish that cellulose wool and polystyrene foam have the lowest heat transfer coefficients.

1. Introduction

Anaerobic digestion of the substrate in biogas plants is becoming increasingly important as it provides high-quality disinfected organic fertilizer and biogas production. Biogas is a gas produced through anaerobic processing of agricultural waste, consisting of a combustible component (methane), a ballast part (carbon dioxide), and minor impurities (hydrogen sulfide). After cleaning, it can be used in heat and gas supply systems, since the energy contained in 1 m³ biogas equivalent to 0.6 energy m³ natural combustible gas, 0.74 liters of oil, 0.65 liters of diesel fuel, 0.48 liters of gasoline. Issues of energy saving and equipment improvement necessitate the biogas plants’ energy efficiency improvement. It is known that in foreign practice BGPs are common in livestock complexes and other agricultural organizations [1]. Russian manufacturers of plants offer their introduction for biofuels for disinfection of wastewater, disposal of organic cattle waste in dairy farms, the remains of straw, silage, weed vegetation, household waste, etc. [2]. The existing biogas plants are located in the Murmansk region (since 2006), village Doshino, Medynsky District, Kaluga Region (since 2009), Vladimir Region, the village of Stary Studenets of the Buinsky Municipal District in the Republic of Tatarstan, (since 2011), the Syumsinsky District in the Udmurt Republic (since 2012), river Luchki, Prokhorovsky District, Belgorod Region (since 2012), Kanash District, Chuvash Republic (since 2012), Orenburg Region (2016). There is a need for the objective study of biogas technologies and the benefits of their
application. The assessment should take into account the potential for biogas production in the region and other quantitative characteristics of technologies that are alternative to centralized gas and electricity supply.

2. Literature Overview
The scientific works of B. Eder, H. Schulz (1996) [3], E.V. Spiridonova (2003) [4], I.A. Trakhunova (2014) [5], V.P. Druzyanova (2016) [6] and other Russian and foreign scientists are essential for increasing the efficiency of aerobic waste processing in biogas plants. The use of biogas produced in power plants to generate electricity and heat was considered by A.A. Kovalev (2013) [7], A.M. Efendiev, S.S. Abramov et al. (2015) [8], A. Purdy, P. B. Pathare, Y. Wang, et al. (2018) [9]. Technical and economic aspects of the biogas technologies introduction were studied by A. Paakkonen, H. Tolvanen, J. Rintala, (2018) [10].

3. Purpose
The objective need to improve the design features of biogas plants, taking into account the technological aspects of generating heat energy, the possibility of using biogas obtained through the farm animals manure processing and other household waste, for the heat supply of separate buildings of an agricultural organization engaged in the production of livestock products, determines the purpose of our study.

3.1 Methods
The methodological basis of the study is a systematic approach and a set of methods for the scientific knowledge of the studied objects and processes. The work uses the calculations of the necessary air exchange for the livestock buildings based on the conditions for the removal of carbon dioxide and water vapor. Thermal power of the heating and ventilation system for a barn for 200 heads, technical characteristics of a biogas plant are determined.

4. Results
Biogas plants differ in the raw materials used, which can be sewage sludge, agricultural waste of plant and animal origin, food industry waste, etc. Sewage sludge has a low nitrogen concentration, a low fiber content, does not require hygienic treatment, the unit is used for their processing equipped with a sand trap, microfilters [11]. Solid waste can be pre-crushed, loaded into the reactor using pumps or a conveyor. To intensify the process of anaerobic digestion of organic waste, an electro-pulse technology that provides grinding of the substrate, activation of the formation of anaerobic microorganisms, and increases the biogas yield, has been developed [15]. By the degree of mobility, biogas plants can be stationary, mobile. The typology of biogas plants is considered in Table 1.

Table 1. Classification of structural and technological schemes of biogas plants

| Grouping features          | Type         | Short description                                                                 |
|----------------------------|--------------|-----------------------------------------------------------------------------------|
| Loading conditions         | continuous   | constant loading of the substrate, uniform biogas production                        |
|                            | quasicontinuous | substrate loading at short intervals - at least once a day                           |
|                            | portioned     | full reactor loading at the initial stage, lack of substrate addition during the working cycle, uneven biogas production |
| System of biogas production| flowing      | continuous or quasi-continuous filling the reactor from the receiving tank           |
|                            | funded        | the reactor is both a fermentation chamber and a sludge accumulator, the disadvantage is the incomplete use of the biogas potential |
combined the installation consists of a receiving tank, a reactor with a gas storage and a closed storage of residues of fermented substrate

The process’ stages
- single stage occurs in one tank, there is no separation at the stage
- multistage the biogas, chambers, reactors’ formation several phases involvement

Reactor shape
- cylindrical a vertical tank located above the ground or deepened into the ground; horizontal reservoir with longitudinal movement of the substrate
- cylindrical with conical part has gas storage space, improved mixing conditions
- rectangular rare use associated with the lack of complete decomposition of the substrate, its mixing

Mixing type
- mechanical realized by traction and kneading mixers
- pneumatic injection of biogas by compressor technology into a liquid substrate
- hydraulic carried out by a stream of liquid using pumps

Production technology
- complete mixing the use of powerful mixing equipment, circulation capabilities
- piston flow use of preemptive effect
- portioned implemented in mobile installations
- special wet fermentation of the substrate; processing of batches of solid waste; fermentation in a film hose

Heating devices
- embedded located inside the reactor
- outdoor external heating system

| Index                          | Type of feedstock |
|-------------------------------|-------------------|
| The volume of raw materials   | cattle manure      |
| tons/day                      | pork manure       |
|                               | bird droppings    |
|                               | silage            |
| The diameter of the bioreactor | 4                 |
| m                             | 4                 |
| Bioreactor volume, m³         | 3.6               |
|                               | 3.6               |
| Volume of biogas produced, m³ | 67                |
| m³/day                        | 67                |
| Electricity generated, kW/h   | 240               |
|                               | 248               |
| Volume of generated heat energy, kWh | 380 |
|                               | 680               |
|                               | 24                |
|                               | 25                |
|                               | 38                |
|                               | 68                |
|                               | 28                |
|                               | 29                |
|                               | 44                |
|                               | 79                |

* Compiled by the authors according to [5, 11, 12, 13].

Table 2. Technical parameters of biogas plants

The study showed that with the same bioreactor parameters, the volumes of biogas produced, the generated electric and heat energy vary depending on the type of substrate. So, with an average size of a dairy farm (100–115 goals), the biogas output will be 240 m³/day, which is equivalent to the generation of electricity and heat in the amount of 24 and 28 kW / h, respectively. The ventilation air flow calculation, heat loss from the building envelope, the heat necessary for heating the supply air, free heat generated by animals, was made for the selected agricultural organization. In the agricultural organization located in the Saratov region, there are 200 heads of cattle. The total heat loss of the enclosing structures of livestock buildings amounted to 71.7 kW (Table 3).
Table 3. Loss of heat of the enclosing structures of the barn for 200 goals

| Type of enclosing construction | Surface area, m² | Calculated heat loss, W | Calculated heat loss, kW |
|-------------------------------|------------------|-------------------------|-------------------------|
| exterior walls                | 475              | 24818.8                 | 24.8                    |
| windows                       | 89               | 7440.4                  | 7.4                     |
| doors                         | 30               | 2280.0                  | 2.3                     |
| ceiling                       | 1540             | 18287.5                 | 18.3                    |
| floor                         | 1540             | 18902.9                 | 18.9                    |

*Calculated by the authors

The thermal capacity of the heating and ventilation system in the livestock building is 148.7 kW. For different operating modes, the biogas plant for the selected organization will have the following dimensions (Table 4).

Table 4. The volume and inner diameter of the digester depending on the biogas plant operating modes’ duration

| Operation mode | Fermentation duration, days | Volume digester, m³ | Inner diameter of digester, m |
|----------------|----------------------------|---------------------|-----------------------------|
| psychrophilic  | 60–80                      | 594-792             | 9.11-10.03                  |
| mesophilic     | 30–50                      | 297-495             | 7.23-8.58                   |
| thermophilic   | 15–25                      | 149-248             | 5.74-6.81                   |

*Calculated by the authors

The heat loss of a biogas plant into the environment will be 1379.4 J / day. To reduce the losses, the bioreactor should be provided with modern thermal insulation (Table 5).

Table 5. Estimated heat loss from the digester to the environment when using various heat-insulating materials in the mesophilic installation operating mode

| Insulating material           | Thickness m | Coefficient heat transfer, W / (m²·°C) | Heat loss per day, W | J |
|-------------------------------|-------------|---------------------------------------|----------------------|---|
| Expanded polystyrene         | 0.15        | 0.29                                  | 4531.6               | 16.3 |
| Cellulose wool                | 0.15        | 0.25                                  | 4004.79              | 14.4 |
| Mineral wool                  | 0.15        | 0.33                                  | 5269.0               | 19.0 |
| Concrete                      | 0.30        | 4.64                                  | 73420.4              | 264.3 |
| Slag concrete                 | 0.30        | 2.00                                  | 31556.9              | 113.6 |
| Concrete and slag concrete    | 0.30        | 1.40                                  | 22114.5              | 79.6 |
| Expanded clay                 | 0.30        | 3.06                                  | 48331.3              | 174.0 |
| Concrete and expanded clay concrete | 0.30    | 1.85                                  | 29221.9              | 105.2 |

*Calculated by the authors

Modern insulating materials have specific properties, contribute to resource saving, the formation of a favorable microclimate in the premises. A comparison of the energy performance of insulating materials made it possible to establish that cellulose wool, polystyrene foam and mineral wool have the lowest heat transfer coefficients. Loss of heat from the digester to the environment in case of cellulose wool will be 14.4 J/day, polystyrene foam – 16.3 J/day, mineral wool – 19 J/day. These materials are used to warm the exterior facades of the buildings, have a low cost of construction and installation.
works. The greatest values of heat loss are observed with the possible use of concrete – 264.3 J/day, and expanded clay concrete – 174 J/day. The graphs of the use of two compared types of insulating materials at an average daily temperature are presented in Figure 1.

![Graph](image)

**Figure 1.** The graph of the dependence of heat loss on the average daily air temperature (January 2019) in the Saratov region when using expanded polystyrene and ecowool for warming a biogas plant

Thus, cellulose wool (ecowool) is the most energy-efficient material. The properties of cellulose wool allow it to be used for warming fire and explosive objects due to the fact that this material prevents the spread of fire, in contrast to other polymeric materials it does not form toxic fumes when heated.

5. Summary

The technological features of the biogas plant’s operation, the foreign and Russian experience of their implementation were studied, a grouping by distinguishing the features (operating mode, biogas production system, stage operation, reactor form, etc.) was carried out. To improve the energy efficiency of a biogas plant, the use of modern thermal insulation materials is proposed. The criteria for energy efficiency are the lowest cost of energy consumed by a biogas plant for its own needs. The lowest heat transfer coefficient is observed when using cellulose wool (ecowool) – 0.25 W/(m²·°C), heat losses from the digester to the environment will amount to 14.4 J/day.

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