Economic and statistical methods of frequency maintenance of biogas plants

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Abstract. The article gives the importance of the technical operation of biogas plants and methods for their determination in the development of alternative energy sources from organic waste. When comparing the two methods in experiments: determining the frequency of maintenance by the acceptable level of reliability and the acceptable value and regularity of changes in the parameter of the technical condition of biogas plants. Their advantage is shown: in simplicity and the possibility of taking into account risk and taking into account the actual technical conditions of biogas plants (diagnostics), in the ability to guarantee a given level of reliability in taking into account variations in the technical condition. Also, the disadvantages of these methods are given, such as the impossibility of making full use of the resource of individual parts of a biogas plant, due to the fact that the frequency of maintenance (П0) is significantly less than the acceptable level of failure-free operation (ñ), in the absence of direct economic assessments of the consequences of biogas plant failures and the lack of direct consideration of economic factors and consequences. The need to receive (or have) information on the patterns of changes in the parameters of the technical condition. In connection with these, the article presents the results obtained by the method of economics and statistics, while it is shown that the technical and economic method is applicable to complex and expensive systems of units and assemblies that do not directly affect the safety of the biogas complex.

1. Introduction
In an agricultural enterprise (farm), a significant amount of organic waste, animal waste, sewage, etc. are collected. Rotting organic waste creates a favorable environment for soil contamination with harmful substances and pathogenic microorganisms.

Calculations show that during the processing of liquid effluents from livestock, poultry farms, and small agricultural farms, as well as organic food waste into biogas (utilization), up to three times more energy can be produced annually than nuclear power plants produce around the world [1, 2]. Closely connected with the problem of waste management is another - increasingly aggravating - environmental protection, which also requires intensive and rational processing of animal waste. The concentration of poultry and livestock, as is known, is associated with the problem of the disposal of farm waste. Modern biotechnology provides for any transformation of the substrate into a feed product and vice versa [3, 4, 5, 6, 7]. The feasibility of such processes is determined mainly by sanitary-epidemiological and, to a lesser extent, technical factors.

The economical use of energy resources is one of the most important tasks of agriculture around the world [8, 9]. In connection with the annual intensive growth of such energy consumers and
mechanisms, the Government of Uzbekistan put forward specific tasks to save hydrocarbon fuel and, as one of the ways to solve the energy problem of the Republic, it is steadily increasing alternative renewable sources [10]. The main directions of the economic and social, as well as ecological culture of the Republic of Uzbekistan for 2020 – 2030 and for the period until 2050 are set the task to ensure the saving of hydrocarbon fuel and replace it with renewable, environmentally friendly energy carriers [11, 12].

The economic strategy of the Republic of Uzbekistan, it is determined that the main goal of the functioning and development of the national economic complex is to ensure intensive economic growth, improve the quality of vital national interests [12].

2. Methods and materials
The standards for the technical operation of biogas plants and the methods for their determination in the development of alternative energy sources from organic waste are very important. As you know, a norm is understood as a quantitative or qualitative indicator used to streamline the process of making and implementing decisions. The standards are used in determining the level of operability of biogas plants, planning the volume of work, determining the required number of performers, the need for a production base, and technological calculations [13, 14, 15]. In our experiments, two methods were compared: determining the frequency of maintenance by the acceptable level of reliability and by the acceptable value and regularity of the change in the parameter of the technical condition [16, 17].

The first method is based on the choice of such rational repeatability of maintenance, in which the probability of failure of an element does not exceed a predetermined value (Figure 1), called risk.

![Figure 1. Determining Maintenance Repeatability on the permissible level of reliability of a biogas plant.](image)

The probability of uptime $P_D$ is determined by the formula:

$$P_D\{x_i \geq Y\} \geq \Pi_0 = X_y$$ (1)

where $R_d$ is the probability of failure-free operation; $x_i$ is MTBF; $V$ is the admissible probability of failure-free operation; $Y = 1 - A$, $\Pi_0$ of the repeatability of maintenance; $X_y$ is a resource.

For aggregates and mechanisms, biogas plants ensuring the safety of the anaerobic process $B_D = 0.9 - 0.98$, and for loading and unloading of organic waste and biofertilizer $B_D = 0.84 - 0.90$. 
Analysis of Figure 1 shows that the repeatability of maintenance defined in this way is significantly less than the mean time between failures and is related to it as follows:

\[ \Pi_0 = \beta \bar{x} \]

where, \( \beta \) is the coefficient of rational repeatability, taking into account the magnitude and nature of the modification of the mean time between failures, as well as the accepted acceptable probability of failure-free operation (Table 1).

| \( B_0 \) | Resource Modification Rate |
|----------|-----------------------------|
| 0.2      | 0.80                        |
| 0.4      | 0.55                        |
| 0.6      | 0.40                        |
| 0.8      | 0.25                        |

In this way, the smaller the variation of the random variable, the greater the repeatability of maintenance, all other things being equal, can be assigned in biogas plants. More stringent reliability requirements reduce the rational repeatability of maintenance.

Thus, one of the main tasks of technical operation is the adoption of technological and organizational measures to reduce the variation in the mean time between failures of preventable elements of a biogas plant:

- improving the quality of maintenance and repair;
- maintaining the assigned intervals regularity of maintenance;
- grouping of parts for specific maintenance by age and operating conditions, providing relative uniformity of technical condition.

The advantage of the first method is its simplicity and the ability to take risks into account. The disadvantages are the impossibility of the full use of the resource of individual parts of a biogas plant, since the frequency of maintenance (\( \Pi_0 \)) is significantly less in terms of the acceptable level of reliability (\( \bar{n} \)) and the absence of direct economic assessments of the consequences of failures of biogas plants [18, 19, 20].

The second method is based on changing a certain parameter of the technical state of biogas plants (methanogens, thermal regime of fermentation, mixing, etc.), which occurs in different ways (curves 1 – 3, 5 – 7 in figure 2).

On average, for a certain parameter of the technical state of biogas plants, the tendency for the parameter to change is characterized by curve 4. From it, as well as the allowable value of the parameter \( Y_{D_0} \), the average operating time \( x_4 = \Pi \) can be determined, when on average the entire set of parts of biogas plants reaches the acceptable value of the parameter of the technical condition.

This average operating time corresponds to the average rate of change of the parameter an according to the graying formula:

\[ Y = a_0 + a_1 \Pi_0 \]

where, \( a_0 \) is the initial value of the technical condition parameter, \( \Pi \) is the operating time, \( a_1, a_2, ..., \) and, \( \beta \) are coefficients that determine the nature and degree of dependence of \( Y \) on \( \Pi \).

At the same time, those products for which the rate of change in the parameter of the technical condition was higher than average (1, 2, 3), \( a_i > a \), reach the limiting state much earlier with operating times \( x_1, x_2, x_3 < \Pi \).
Figure 2. Scheme for determining the frequency of maintenance by an acceptable value and patterns of changes in the parameter of the technical condition.

Consequently, for biogas plants with an assigned periodicity $\Pi$ with probability $F_\Pi = 0.5$ a failure will be recorded. Such a system for servicing biogas plants is irrational, therefore, a periodicity of $\Pi_0 < \Pi$ is prescribed at which the probability of failure will not exceed the specified risk value $A$, for example, $A = A_2$. This case corresponds to a greater intensity of the change in the technical condition parameter than the average, called the maximum allowable, i.e. $\alpha_d = \mu a$, where $\mu$ is the coefficient of the maximum intensity of the change in the parameter of the technical condition, and the condition must be met:

$$P_D\{a_i \leq a_d\} = 1 - A = Y$$

(3)

The coefficient $\mu$ is affected by the degree of risk, the variation of $v$, and the form of the law of distribution of a random variable.

For the normal distribution law:

$$M = 1 + t_D v$$

(4)

where, $t_D$ is the normalized deviation corresponding to the confidence level of probability.

For the Weibull-Gnedenko Law:

$$\mu = \frac{-m}{\sqrt{\ln 1 - P_D}}$$

(5)

where, $G$ is gamma function; $m$ is the distribution parameter.

The greater $v$ or $P_D$, the greater $\mu$ and the less optimal the frequency of maintenance of biogas plants. This method is used for objects with a fixed change in the technical condition parameter.

The advantage of the second method was to take into account the actual technical condition of biogas plants (diagnostics) and to be able to guarantee a given level of reliability, taking into account variations in the technical condition. The disadvantages of the method are the lack of direct accounting of economic factors and consequences and the need to obtain (or have) information about the patterns of changes in the parameters of the technical condition [10].

3. Results and discussion

Based on the foregoing, we have proposed economic and static methods for determining the frequency of maintenance of biogas plants. These methods are reduced to determining the total unit costs for maintenance and repair and minimizing the work carried out in a power plant based on renewable types of energy. The minimum cost corresponds to the optimal frequency of maintenance. In this case, the specific cost of maintaining a biogas plant:
\[ OI = S / \Pi \]  

(6)

where \( \Pi \) is the frequency of maintenance; \( S \) is the cost of performing the maintenance operation. With increasing periodicity \( \Pi \), one-time maintenance costs \( (S) \) remain constant or increase slightly, and unit costs are significantly reduced (Table 1).

| The frequency of checking for leaks, day | Large amount | small volumes |
|-----------------------------------------|--------------|--------------|
| 100                                     | 100          | 100          |
| 150                                     | 72           | 74           |
| 200                                     | 58           | 55           |
| 250                                     | 51           | 42           |
| 300                                     | 65           | 30           |

Table 2. Influence of periodicity \( \Pi \) on the cost \( S \) of biogas leakage and biomass of large and small volumes, %

An increase in the frequency of maintenance, as a rule, leads to a reduction in the resource of units or assemblies and an increase in unit costs for the frequency of repair of biogas plants:

\[ \text{Op} = \frac{3p}{\Pi} \]  

(7)

where \( 3p \) is repair costs for the sum of 100 days; \( P \) is resource before repair, 24 hours.

The expression \( u = OI + OII \) is an objective function of extreme value, which corresponds to the optimal solution. In this case, the optimal solution corresponds to a minimum of unit costs. The determination of the minimum of the objective function and the optimal value of the maintenance frequency is carried out graphically (Fig. 1) or analytically if the dependencies \( OI = f(\Pi) \) and \( OII = \Psi(\Pi) \) are known.

Figure 3. Determining Maintenance Frequency by the technical and economic method of a biogas plant.
If, when assigning the risk level, the losses associated with oxygen access to the anaerobic process are taken into account, the technical and economic method is applicable to determine the optimal frequency of operations that affect the non-stop operation of biogas plants.

The advantage of the method lies in the possibility of taking into account the economic consequences of decisions \( (P_0) \), easily accessible to understanding, clarity, and for a variety of applications.

Long-term experiments conducted (from 2015 to 2019) on a production biogas plant (figure 4) showed several drawbacks of the proposed method. However, these shortcomings are related to human factors.

![Figure 4. Biogas complex installed on a cattle farm owned by the Bukhara oil refinery.](image)

4. Conclusions
The considered economic and static methods for determining the frequency of maintenance of biogas plants reveal the shortcomings and show the need for reliable information about the cost of maintenance and repair operations, as well as the effect of the frequency of maintenance on increasing the resource of units and units of a biogas plant.

Besides, when using the proposed method, it is impossible to take into account the variation of all indicators \( (II) \) is the frequency of maintenance; \( S \) is the cost of performing maintenance operations, \( x \) is the mean time between failures, \( O \) is the unit cost of maintenance, \( 3p \) is the cost of repair) and it is impossible to guarantee a certain level of uptime of biogas plants which does not reduce the advantage of the method.

Economic and static methods are applicable for complex and expensive systems of biogas plants that do not directly affect safety, such as a gas tank under varying biogas pressure, a compressor, a gas generator - converting biogas into electricity (units, assemblies, changing biogas filters, cleaning a pit of organic waste pretreatment, replacement of sieve separation of inorganic substances).

Gratitude
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