Checking the reliability of biogas installations by stimulation models of markov processes on faults tree

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Abstract. This article describes the evaluation of biogas plants’ reliability using Markov processes stimulation models and faults tree methodic. Human factors and climatic circumstances are important in the main factors of biogas plants reliability but weren’t explored up to now in cause of its peculiarity and intricacy of exposition. Described methodic is a novelty in biogas technologies exploration, especially in Uzbekistan where there are issues of biogas implementation.

1. Introduction
The complexity of the technological processes occurring inside and outside the biogas plant, the inability of operatively covering the whole spectrum of phenomena that can lead to emergencies, makes it advisable to use the method of event trees (fault trees) for a comprehensive analysis of the stability of functioning and environmental safety of biogas technologies. The fault tree is a deductive logical construction using the concept of one final event (as a rule, an accident, or a failure of an element of the entire biogas plant system) to find all possible ways in which it can occur [1-5].

2. Methods
There are situations when a failure occurs only with a certain order of occurrence of input events (failures) or if certain time conditions are met (for example the action of a factor over a certain time interval), which is more than acceptable, or with some combination of these requirements. In this case, the construction and analysis of fault trees are much more complicated [6, 8, 9, 12].

Some terms necessary to understand the questions of this methodic:
- Event - an unwanted deviation from the norm or the expected state of the system components.
- The main (upper) event is an undesirable event or incident at the top of the fault tree, from which they go down using the logical gate.
- An intermediate event allows you to combine various initial events that are considered in development using conditions.
- The initial event is an equipment failure or personnel error, which, when considered, is not broken down into separate composite events of a smaller scale.
- Non-developing event - possible causes of an undesirable event are not considered in development since the conditions for the occurrence of this event are not reliable or the information available is not enough.
• Condition (logical gate) - a logical connection between input events (lower level events) and individual output events (higher level).
• The “and” condition combines input events, each of which must exist simultaneously with the others.
• The “or” condition is used if, to determine a subsequent output event, it is enough to enter data on one of any previous events.
• A minimum set of sections - the minimum number of chains of events at which the main event can occur. All events (failures) correspond to a basic or non-developing event. Most of the existing methods for analyzing fault trees are based on the search and study of many tree sections and paths.
• The path (section) is a combination of basic events, the implementation of which leads to the appearance of the main event.
• Section (path) is such a combination of basic events, the simultaneous unrealization of which leads to the impossibility of the occurrence of this event.
• A minimum path is a group of events or primary sources of failure that can lead to the main event through a minimum number of steps.

From the point of view of emergency situations, it is preferable to analyze the minimum tree paths. Knowing the probability of their implementation, we can calculate the probability of the main event. If the problem of increasing the reliability of systems is solved, then it is much more efficient to analyze the minimum sections of the fault tree to find the simplest ways to increase the reliability of the system [7, 11 13, 15].

The combination of these considerations allows in finding the most “bottlenecks” of the system, effective ways to improve the reliability of the biogas installations.

From the above consideration, it is clear that the concept of event and failure trees is a promising method for solving the problem of reliability and safety, as well as determining the risk of the functioning of the vehicle.

3. Results and Discussion

Research is used to:
• identifying all the paths that lead to the main undesirable event under a certain set of circumstances;
• determining the minimum number of combinations of events that can lead to the main event;
• qualitative determination of the main causes of an undesirable event;
• quantitative assessment of the frequency of the probability of an undesirable event;
• identification of the general nature of failures or their common causes that are difficult to identify when considering isolated subsystems;
• analysis of the sensitivity of individual events to deviations of system parameters.

Four classes of causes of failure of biogas plants can be distinguished:
• equipment failures;
• deviations from technological regulations;
• errors of production personnel;
• external causes (natural disasters, natural factors).

One of the advantages of the method is a systematic, logically justified construction of many failures of system elements that can lead to a shutdown of biogas plants.

Each event is marked accordingly:

* B is for basic or undeveloped events,
* M is for intermediate events,
* T is the main event.
The main events in the fault tree are those that start with event $T$ (where the biogas plant stops working) and identify all the events that cause it. We can highlight the following key factors:

- $M1$: interruptions in operation due to a malfunction of the system, mechanism, and components of the biogas plant;
- $M2$: interruptions due to the external environment (climatic factors);
- $V1$: interruptions due to operator error;
- $M3$: anaerobic process failure;
- $M4$: Interruptions due to poor alert system.

As seen in Figure 1, events $M1$, $M2$, $M3$, and $M4$ require additional development. Since there is enough data for event $V1$, we can consider it as the main event. The analysis may shift to some extent until all causal mechanisms are correctly understood. Consider the small supporting events that lead to them (Table 2) [16, 17, 18, 19].

![Figure 1 Initial diagram of the key events algorithm in the fault tree](image)

**Table 1. Small supporting events**

| Malfunction name | Significance level and score (B1) | Frequency level and score (B2) | Detectability and score (B3) | R.P.N. $^3$ |
|------------------|-----------------------------------|--------------------------------|-----------------------------|-------------|
| B1               | II-8                              | I-9                            | 2                           | 144         |
| B2               | Errors and interruptions in the speed of loading and unloading | II-7 | I-9 | 1 | 63 |
| M5               | The occurrence of errors and malfunctions in the production of biogas and bioorganic fertilizers | II-7 | II-7 | 2 | 98 |
| M6               | Faults associated with overfilling of containers | II-7 | II-8 | 1 | 56 |
| B7               | Failure or clogging of the connecting equipment for the loading and unloading process | II-8 | II-7 | 1 | 56 |

$^1$ Significance level: I-Catastrophic, II-Hazardous, III-Major, IV-Minor

$^2$ Frequency level: I-Frequent, II-Reasonable Probable, III-Occasional, IV-Remote, V-Extremely Unlikely

$^3$ Risk Priority Number = $B_1 * B_2 * B_3$
|   | Description                                                                 | Code 1 | Code 2 | Code 3 |
|---|------------------------------------------------------------------------------|--------|--------|--------|
| B8 | The formation of sediments and crusts on the vessels                        | II-7   | II-8   | 1      |
|    | Overloading of connecting mechanisms during loading and unloading           |        |        | 56     |
| B9 | Changes in temperature and humidity in the air                              | IV-4   | I-9    | 1      |
|    | Deterioration of equipment and materials due to changes in temperature and humidity in the air | II-8   | II-7   | 1      |
|    | Changes in the loaded mass due to changes in temperature and humidity in the air | III-6  | I-9    | 1      |
|    | Under the influence of the factors specified in M7, the device increases or decreases the temperature, which is not characteristic of the thermal regime in the vessels | IV-5   | I-9    | 1      |
| B11 | Natural disasters                                                           | I-9    | III-6  | 1      |
|    | Defective or non-existent insulation materials against environmental influences | II-7   | II-7   | 1      |
| B12 | Errors that externally affect the anaerobic process                         | II-7   | II-8   | 1      |
| B13 | Violation of the tightness of vessels (I, II)                               | I-9    | III-6  | 1      |
| B14 | Errors related to a substrate (loading mass)                                | III-6  | II-7   | 1      |
| B15 | Substrate obsolescence                                                       | IV-4   | II-7   | 1      |
| M8 | The presence of additives in the substrate that stop the anaerobic process  | III-6  | II-7   | 1      |
| B16 | Non-compliance of the substrate with mechanical requirements during         | III-6  | II-7   | 1      |
| B17 |                                                                               |        |        | 42     |
| B18 |                                                                               |        |        | 42     |
| Code | Description                                                                 | Column 1 | Column 2 | Column 3 | Column 4 |
|------|-----------------------------------------------------------------------------|----------|----------|----------|----------|
| B19  | Improper selection of substrate composition                                | IV-4     | III-6    | 1        | 24       |
| M9   | Errors that internally affect the anaerobic process                         | III-6    | II-7     | 1        | 42       |
| M11  | Errors during the process inside the bioreactor                             | III-6    | I-9      | 1        | 54       |
| B20  | Air infiltration into the bioreactor                                         | II-8     | III-6    | 1        | 48       |
| B21  | Violation of heat regimes                                                   | III-6    | II-7     | 1        | 42       |
| B22  | Sedimentation and crust formation in the bioreactor                         | II-8     | II-7     | 1        | 56       |
| B23  | Moisture does not meet the requirements of the anaerobic process            | II-7     | II-7     | 1        | 49       |
| B24  | Possible excess of pressure and humidity                                    | I-9      | II-7     | 1        | 63       |
| M12  | Device malfunction warning systems                                          | I-9      | II-7     | 1        | 63       |
| B25  | Fault of warning system failure warning sensors to stabilize the pressure in vessels | I-9      | III-6    | 1        | 54       |
| B26  | Fault of sensors that warn of changes in temperature and humidity in containers | II-7     | III-6    | 1        | 42       |
| B27  | Faults in the sensors that warn that the tightness of the containers has been compromised | I-9      | III-6    | 1        | 54       |
| M13  | Errors in the ASU system                                                    | II-7     | II-7     | 1        | 49       |
| B28  | Faults in the ASU system                                                    | II-8     | II-7     | 1        | 56       |
| B29  | Failure of the ASU system to respond to emergencies                        | I-9      | IV-5     | 1        | 45       |
| B30  | Faults in the ASU system under external influences                          | II-7     | III-6    | 1        | 42       |
| M14  | Fault of equipment that responds to safety conditions                       | I-9      | IV-5     | 1        | 45       |
| B31  | Failure of safety relief                                                    | I-9      | IV-5     | 1        | 45       |
valves

|   |   | I-9 | IV-4 |   |   |
|---|---|-----|------|---|---|
| B32 | Exhaust flare failure |   |   | 1 | 36 |
| B33 | Valve failure | II-7 | II-7 |   |   |

The events in table 1 must be compiled in a prescribed manner. Thus, the event will look like this:

(2)

\[ \text{(2)} \]

\[ a) \]

\[ b) \]

\[ c) \]

\[ d) \]

Figure 2. Failure algorithm for all factors: a) M1, b) M2, c) M3, d) M4

Once we have identified the factors through the subcategories generated by the additional events shown in Figure 2, we can combine all the schemes and create a failure algorithm (Figure 3). We must follow the path of analyzing the minimum set of cuts. This should easily determine the possible combination of the faulty device. We may notice that biogas device user errors are the minimum
combination and the shortest version of the algorithm. It is necessary to find a way to determine possible combinations of equipment failures that lead to an undesirable event.

In this case, the shortest path calculation algorithm may consist of two steps:
- compiling a list of possible routes;
- Build a series of matrices.

This method is best implemented by analyzing the least imagination. However, at the first observation, the 5 main paths leading up are identified. For example $B1, B3 - B6$. At this stage, we need to consider minimal reductions to ensure that they all represent real, possible events.

If the circuit repeats events in different directions separated by “AND” conditions, the calculations will be sensitive to numerical errors in the calculated frequency of the main event.

The calculation method starts with the main events in the field and moves towards the main event. The mathematical dependence of the calculations is shown in Table 3.

It should be remembered that the input contains several probabilities for the "AND" condition and one frequency for the "OR".

Having a finite biogas plant failure tree diagram and an estimated frequency (probability) for each base or non-developing event, we can calculate the failure frequency.

The calculation is sensitive to digital errors in the predicted frequency of the main event if the tree has repeating events in different branches, which are separated by the condition "and".

The calculation method starts with the basic events in the fault tree and moves up to the main event. The mathematical relationship for the calculations is given in Table 2.

### Table 2. Mathematical connection for calculations

| Condition | Input pair $(B), (C)$ | Calculation of output $(A)$ | Time to year |
|-----------|-----------------------|----------------------------|-------------|
| «OR»      | $P_B \text{ «OR» } P_C$ | $P_A = P_B + P_C - P_B P_C = P_B + P_C$ | $t^1$       |
|           | $F_B \text{ «OR» } F_C$ | $F_A = F_B + F_A$          |             |
|           | $F_B \text{ «OR» } P_C$ | is not allowed              |             |
| «AND»     | $F_B \text{ «AND» } P_C$ | $P_A = P_B P_C$            | $t^1$       |
|           | $F_B \text{ «AND» } F_C$ | is not allowed              |             |
|           | $F_B \text{ «AND» } P_C$ | convert to $F_B \text{ «AND» } P_C$ |             |

where: $R$ is the probability; $F$ is the frequency (time$^{-1}$)

One of the two most important logical functions in the main algorithm is the “AND” symbol, which should be considered when using:

(a) the output is derived from the input in the form of interruptions in preventive (protective) actions;
(b) the output comes from the input in the form of interruptions in the work of preventive (protective) equipment;
(c) the output is extracted from the input in the form of interrupts of two parallel devices;
(d) The output comes from the input in the form of interruptions of two faults.

The difference between these systems is not a problem in the development of the algorithm, but difficulties may arise at the evaluation stage. As described above, the probability of $R_0$ with the output of the “And” sign with two input data is as follows: if the probability of the input events is equal to $P_1$ and $P_2$,

$$P_0 = P_1 P_2$$  \hspace{1cm} (1)
This may be characterized by the frequency or probability of the event or not. Device failure is usually expressed by the frequency and failure of preventive actions or the likelihood of safety devices.

Protective equipment should normally be checked periodically for malfunctions. Information about the interruption of such devices can also be reported in the form of probability and frequency of interruption. Their relationship is as follows:

\[ p_0 = f_0 \cdot \frac{p}{2} \quad (2) \]

where: \( r \) is the probability of failure, \( f \) is the degree of failure, \( \tau \) is the interval then the frequency for example (a) is expressed as follows:

\[ f_0 = f_r \quad (3) \]

Equation 2 can also be used for the situation in type (B), in which case the probability of interruption in the guarantees is given in equation 1.

(c) The assessment of the condition is less clear. For this, we can use approximate models of parallel systems derived from Markov or obtained by the method of additional (fixed) density functions. They give output probabilities where events are represented as input frequency. In this case, to convert a probability into frequency, the rare event approximation is used:

\[ f = \frac{p}{t} \quad (4) \]

Then the corresponding models for (d) are used. The mechanism of action can be used to analyze the sensitivity of individual events to deviations of system parameters. Significance analysis is determined by collecting the minimum cross-sections as a contribution to the system failure rate.

For quantification, it’s necessary to carefully study the recurring events that can lead to a digital error. As seen there no recurring events. We need to include numerical values of frequency (per year) or probabilities (unweighted) for each major event. The calculation starts at the bottom of the tree and continues up. Below are the calculations for the left corner of the event:

When event M9 occurs between B15 and B16 together, we increase the probability:

\[ P(M_9) = P(B_{15}) \cdot P(B_{16}) = 1 \cdot 10^{-2} \cdot 1 \cdot 10^{-2} = 1 \cdot 10^{-4} \text{ per year}^{-1} \quad (5) \]

There are 4 events going to the M10 through the BA and most likely:

\[ P(M_{10}) = P(B_{17}) \cdot P(B_{18}) \cdot P(B_{19}) \cdot P(B_{20}) = 1 \cdot 10^{-3} \cdot 1 \cdot 10^{-2} \cdot 1 \cdot 10^{-1} \cdot 1 \cdot 10^{-1} \approx 1 \cdot 10^{-7} \text{ per year}^{-1} \]

Events M_{10} and M_9 are sent to M_5 through a logical block OR:

\[ P(M_5) = P(M_9) + P(M_{10}) = 1 \cdot 10^{-4} + 1 \cdot 10^{-7} \cdot 1 \cdot 10^{-4} \text{ per year}^{-1} \quad (6) \]

\( M_1 \) is an intermediate event that occurs with a frequency of B 2 and M5 with the following probabilities:

\[ F(M_1) = F(B_2) \cdot P(M_5) = 300 \cdot \text{year}^{-1} \cdot 1 \cdot 10^{-4} = 3 \cdot 10^{-2} \text{ per year}^{-1} \quad (7) \]

Other frequencies and probabilities were calculated in this way, and the frequency of the main event T was calculated.

\[ M_1 = 3 \cdot 10^{-2} \text{ per year}^{-1}; \quad M_2 = 3 \cdot 10^{-5} \text{ per year}^{-1}; \quad B_1 = 1 \cdot 10^{-4} \text{ per year}^{-1}; \]

\[ M_3 = 2 \cdot 10^{-2} \text{ per year}^{-1}; \quad M_4 = 2 \cdot 10^{-5} \text{ per year}^{-1}. \quad (8) \]
4. Conclusions

Thus, the calculation and compiled trees cause to the conclusion that biogas was the first shortest segment of biogas devices by mistake of the operator, and then the greatest likelihood of device failure was caused by technological failures, systems, and connections.

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