Study of the main parameters of the household waste hydroseparation system

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Abstract. The article explores the development of new biotechnologies; recycling and maximum waste detoxification and ecologisation of industrial and agricultural production; improvement of technological processes of land reclamation and land protection. The authors developed a methodology for assessing the environmental friendliness of recycling processes and a hydroseparation system to ensure environmental safety in waste management under natural and man-made influences. They investigated the properties of household waste and established the extent of their impact on environmental protection. The research developed a device for hydro-separation of household waste, supported by a utility model and equipped with a central rotor drum for mixing and crushing household waste in the hydroseparation chamber. The authors propose a methodology for calculating the reliability of systems using a logical scheme and a verbal formula to determine the dependence of the system reliability function on the reliability functions of the blocks, i.e. by compiling a logical model of the failure-free operation of the system.

1. Introduction
At present, the increase in municipal solid waste in the Russian Federation is far greater than the increase in recycling. The constant increase in the cost of disposal.

At the same time, the cost of household waste disposal in landfills is increasing. The constant growth of household waste disposal costs and the growing shortage of disposal areas leads to an increase in the number of unauthorized landfills (3...4 times more than the number of registered landfills).

We should note that the protection of the natural environment requires the application of engineering protection against pollution and other types of anthropogenic impacts.

The main areas of focus include:
- research and implementation of resource-saving, waste-free and low-waste technologies;
- new biotechnologies, recycling and maximum waste detoxification and greening of industries.

Many national and foreign scientists have carried out research in this field: A.I. Golovanov, V.I. Smetanin, V.N. Dzhumagulova N.T., F. Sissot, et al. They have studied waste management processes and closely related technological processes of land reclamation and land protection [1–4].

At the same time, a long-standing consumerist attitude towards nature and the compensation of energy and material shortages by increasing energy and material production has resulted in inefficient use of over a fifth of the gross social product in the Russian Federation.

This makes the issues of household waste recycling and the research, development and justification
of the parameters of new low-waste resource-saving systems and technologies for the separation and recycling of industrial and agricultural wastes topical.

2. Statement of the problem and ways to solve it
To achieve the goal of justification of applying household hydroseparation we set the following objectives: research and development of a methodology to assess the environmental friendliness of technological processes; development of hydroseparation system to ensure the environmental safety of waste management under natural and man-made impacts; study of household waste properties and determining the degree of their impact on the protection of environment.

The scientific novelty and practical significance of this work lie in the development and study of household waste hydroseparation system functioning under conditions of possible natural and man-made impacts, as well as in the development of methods for assessing the economic feasibility of processing various components of household waste, determining the technological sequence of sorting modules.

3. Results
This paper presents the development of an environmental monitoring system at facilities with waste disposed at them, presents the concept and structure of environmental rationing, provides methods for determining waste generation standards, and provides a methodology for calculating the redundancy reliability of complex systems according to sensitivity balancing criteria.

As a rule, the variable element in monitoring systems is the controlled object. Along with other automatic control tasks, it is necessary to reduce the sensitivity of the system to possible unforeseeable changes in the parameters of the controlled object.

One effective method of optimizing the reliability of such systems is the sensitivity balancing method for individual elements.

The basis of this technological approach is that the lower the sensitivity (or sensitivity function), the less influence the transfer function of the considered element has on the properties of the system. Therefore, the system has greater reliability.

Therefore, it is relevant to develop a highly efficient mathematical apparatus for optimizing reliability performance according to various criteria simultaneously under several constraints.

In this connection, apart from existing methods for optimizing the reliability of complex systems (dynamic programming, uncertain Lagrange multipliers, descent, etc.), it is scientifically and practically interesting to consider the theory of sensitivity balancing by individual elements.

We consider a mathematical apparatus for optimizing the reliability performance of a complex system under several constraints.

Considering the accepted constraints, the theorem proved and using the lemma [5, 6] we obtained the following algorithm.

We take a derived integer $K$ that satisfies the inequalities

$$1 \leq K \leq n - 1; \ K \leq m$$

and take a random number of integers $i_1, \ldots, i_k$ satisfying inequalities

$$1 \leq i_1 \leq \ldots \leq i_k \leq m$$

Then solve a system of equations

$$C_{i_1}(P) = \ldots C_{i_k}(P) = 0$$

Together with a system of equations equal to the lemma previously adopted.

If $P$ is a solution of the system corresponding to these equations, then it is suspected to be an extremum, if in addition $P$ satisfies a system of $n - k$ inequalities, in this case we put $P$ into the set $M$.

$$C_j(P) \leq C_{i_0}; \ j \neq i_j, \ j \in \{1, k\}$$

If $P$ does not satisfy the system of inequalities (4), it is simply discarded. Trying in this way all possible integers $K$ satisfying inequalities (1), and all possible sets $i_1, \ldots, i_k$ satisfying inequalities (2), we obtain the set $M$ of points suspicious of an extremum.

Next, there are two possible options:
1) If \( m < n \), we get

\[
P_{\text{max}} = \max_{p \in M} P(p),
\]

and as points \( p^* \), take the point that \( P(p^*) = P_{\text{max}} \).

In this case, point \( P^* \) gives the maximum reliability under constraint (1).

2) If \( m < n \), consider a random set of integers \( i_1, \ldots, i_n \) satisfying the inequalities

\[
1 \leq i_1 < \ldots < i_n \leq m
\]

and solve a system of equations

\[
C_{i_1}(P) = \ldots = C_{i_n}(P) = 0
\]

Obtained from system (7) points \( P \) satisfying a system of inequalities

\[
C_i(P) \leq C_{i_0}; \quad i \neq j, \quad j \in \overline{1,n},
\]

are also suspected extremes and entered into the \( M \) set.

Points that do not satisfy (8) are simply discarded.

Trying all possible sets satisfying inequalities (6), we get the whole set of \( M \) points suspicious of an extremum. This completes the algorithm for finding points \( P^* \) where the maximum reliability \( P \) is achieved under constraint (1).

Thus, we propose a new mathematical method of determinant equalization which is designed to solve a wide class of system reliability optimization problems under several constraints.

The substantiation of the necessity of using a modular system for household waste processing, the proven need for the use of hydroseparation technology for additional extraction of small fractions of valuable components from household waste and the results of our experiments formed the basis of our developed device for hydroseparation of household waste, protected by the Russian patent for a utility model [6, 8].

The device belongs to the field of household waste disposal and aims at separating the mixture in water into floating suspended and drowned ingredients.

There is a known installation for hydroseparation of household waste using compressed air, containing a hydroseparation chamber, in which belt conveyors are installed for the removal of heavy ingredients and small ingredients that are carried to the surface by air currents. [System for separating waste materials by enhanced flotation, 02976, B03B 7/00]

The disadvantage of the counterpart is the lack of a device for removing suspended ingredients from the hydroseparation chamber and the use of compressed air in the hydroseparation process.

The closest to our proposed device is a device for hydroseparation of household waste, containing an open hydroseparation chamber, in which a belt conveyor is installed with the feeding of sunken ingredients into the container, and a side spillway with a drum - rotor discharges floating ingredients with some water onto a belt conveyor, installed at the outer wall of the hydroseparation chamber. [Apparatus for separating and removing floatables, US 3568839, BO1d 21/12, 1971].

The disadvantages of this prototype are the lack of a device for mixing and shredding household waste and removing suspended ingredients from the hydroseparation chamber and the inefficient design of the rotor drum with flexible baffles.

The technical result, which is the objective of the present useful model (Figure 1) is to eliminate the drawbacks of known devices by placing in the hydroseparation chamber a central rotary drum for movement and shredding of household waste, placing between the complex hydroseparation chamber for accumulation of suspended ingredients. The side drum-rotor is designed with sectors - buckets with perforations on the base walls for water outlet from sectors - buckets.
As a rule, the calculation of system reliability follows the preliminary work of drawing up a logical calculation scheme.

This work involves 3 stages:
- describing the operation of the system;
- classifying waste elements and systems;
- drawing up a structural (logical) model of the failure-free operation of the system.

Each unit of the system has a reliability function calculated according to the selected calculation methodology. All highlighted blocks are numbered or identified by a letter. It then lists the combinations of units that ensure the trouble-free operation of the system. These combinations can have a table form.

| Combination number | The system must have functioning units to ensure the trouble-free operation |
|--------------------|--------------------------------------------------------------------------------|
| 1                  | A, B, C, D, E, F.                                                             |
| 2                  | A, B, K, D, E, F.                                                             |
| 3                  | T, M, P, D, E, F.                                                             |
| 4                  | T, M, S, D, E, F.                                                             |

Table 1 provides a verbal formula: "Fail-safe system operation is ensured if the units A and B and C (or K) or T and M and P (or S) and D, E and F are serviceable".

Together with this verbal formula, it is sometimes more convenient to make a Figure 2 logic diagram, where the word 'and' corresponds to a series of blocks [7]. This is not a functional diagram, but a logical scheme for calculating reliability.
Figure 2. Example of a logic diagram for calculating system reliability

From the conducted logic diagram of Figure 2 or the verbal formula, it is possible to make a dependence of the reliability function of the system on the reliability function of the blocks.

For a system with the calculation logic shown in Figure 2, the probability of no-failure operation will be:

\[ P = [1 - (1 - P_1)(1 - P_2)]P_3 \]  \hspace{1cm} (9)

where \( P_1, P_2, P_3 \) is the probability of failure-free operation for a given time \( t \) of the respective groups of units marked with a dotted line in Figure 2.

Then the failure probability of the first group of units is as follows:

\[ P_1 = P_K P_B [1 - (1 - P_C)(1 - P_K)] \]

For the second group of blocks, it is as follows:

\[ P_2 = P_T P_M [1 - (1 - P_P)(1 - P_S)] \]

For the third group of blocks, it is as follows:

\[ P_3 = P_D P_E P_F \]

By substituting these expressions for the block groups into formula (1), we obtain a system reliability function:

\[ P(t) = 1 - [1 - P_A(t)P_B(t) [1 - (1 - P_P(t)(1 - P_S(t)))] [1 - P_L(t)P_M(t)[1 - (1 - P_P(t)) \cdot (1 - P_S(t))] P_D(t)P_E(t)P_F(t). \]  \hspace{1cm} (10)

Figure 2 shows the general scheme to which formula (2) corresponds.

4. Conclusion

Thus, this work highlights a wide range of national economic tasks to ensure environmental safety and environmental protection activities of the population in terms of the most effective use of new methods and technical means for the technological process of hydro-separation of household and industrial waste.

The authors developed a methodology for assessing the environmental friendliness of recycling processes and a hydroseparation system to ensure environmental safety in waste management under natural and man-made influences.
They propose a methodology for calculating the reliability of redundancy of complex systems by the criteria of balancing the sensitivity of the system in relation to possible unforeseen changes in the parameters of the controlled object, as well as the methodology for calculating the reliability of systems by compiling a model of no-failure operation of the system.

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