

PAPER • OPEN ACCESS

## Optimum planning of experimental research at the biogas plant

To cite this article: V A Lomazov *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **659** 012111

View the [article online](#) for updates and enhancements.



**240th ECS Meeting** ORLANDO, FL

Orange County Convention Center **Oct 10-14, 2021**

Abstract submission deadline extended: April 23rd

**SUBMIT NOW**

# Optimum planning of experimental research at the biogas plant

V A Lomazov<sup>1,2</sup>, V I Lomazova<sup>2</sup>, I V Miroschnichenko<sup>2</sup>, D A Petrosov<sup>3</sup>  
and A L Mironov<sup>1</sup>

<sup>1</sup> Belgorod State Agricultural University named after V. Gorin, 1, Vavilova st., Mayskiy, Belgorod region, 308503, Russia

<sup>2</sup> Belgorod State National Research University, 85, Pobedy st., Belgorod, 308015, Russia

<sup>3</sup> Financial University under the Government of the Russian Federation, 49 Leningradsky Prospekt, Moscow, 125993, Russia

E-mail: lomazov@yandex.ru

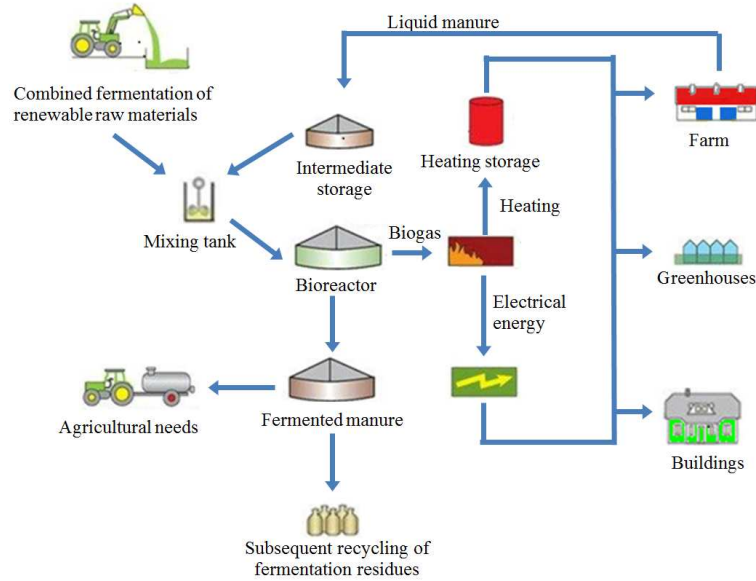
**Abstract.** Biogas energy, being one of the important components of ecological agricultural production, on the one hand, allows you to conduct successful disposal of crop and livestock waste, receiving organic fertilizers, and on the other hand makes it possible to provide heating and electricity to greenhouses, farms and other industrial buildings and buildings. At the same time, bioenergy technologies require improvement and development, taking into account the specifics of the agro-industrial complex in which they are used. The problems of organizing scientific research at a biogas station are considered. Based on the analysis of the functioning of the biogas plant, a mathematical formulation of the problem of constructing a schedule for conducting experiments taking into account the costs of equipment retooling is formulated. To determine the coefficients of the objective function of the constructed optimization problem, it is proposed to use expert technologies and a fuzzy inference procedure based on a fuzzy production model of knowledge about the subject area. To construct a solution to the optimization problem, along with the classical methods of discrete linear optimization, it is proposed to use evolutionary genetic algorithms that are effective in solving problems of large dimension.

## 1. Introduction

Biologization and environmentalization of agricultural production imply an increasing use of alternative renewable green energy sources [1]. The undoubted advantage of biogas energy technologies for a multi-profile agricultural enterprise (Figure 1) is the complexity of solving such problems as ([2]):

- utilization of animal husbandry waste (in order to avoid agrogenic soil contamination);
- production of fertilizers (within the framework of organic agricultural technologies);
- provision of heat and electricity (to supply remote agricultural premises).





**Figure 1.** Scheme of inclusion of a biogas station in a multi-profile agricultural economy

However, the use of biogas technologies is hindered by a number of negative factors:

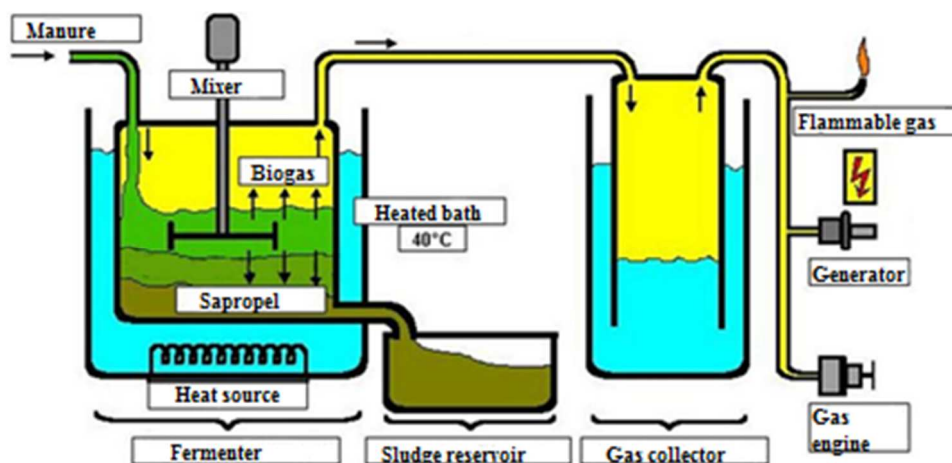
- high cost and significant payback period of biogas plants;
- desirability of placement near sources of raw materials and consumers of thermal (electric) energy;
- combustion products contain harmful substances.

These factors justify the need for scientific research aimed at improving the technology. A feature of biogas technological processes is a significant dependence of the result on the parameters of biomass, temperature regime, pressure in the bioreactor and other technological parameters, which can only be determined experimentally [3].

The purpose of this work is to study the possibility of reducing the cost of experimental research by organizing experiments.

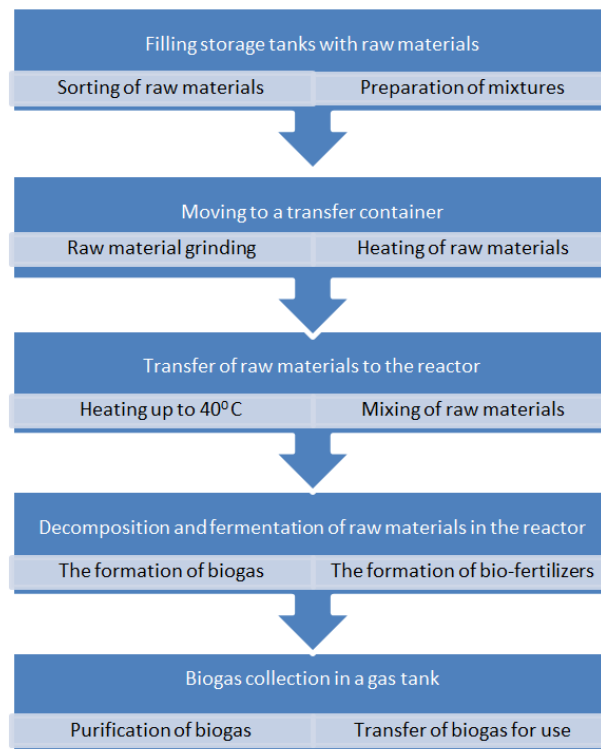
## 2. Materials and methods

The principle diagram of a biogas plant (in accordance with [2,3]) is shown in Figure 2.



**Figure 2.** The schematic diagram of a biogas plant

The biogas obtaining process contains the technological operations shown in Figure 3.



**Figure 3.** The basic technological operations in the production of biogas

The duration and cost of individual technological operations, as well as the volume and energy value of the resulting biogas are largely determined by the type of raw material used, the selection of which (and the corresponding technological parameters) is usually determined experimentally. At the same time, for the purity of experiments, it is necessary to reconfigure the equipment and, in particular, to thoroughly clean the remains of the raw material mass and bio-fertilizers accumulated in the reactor tank when replacing raw materials in the preparation of a new experiment. At the same time, for the purity of experiments, it is necessary to reconfigure the equipment and, in particular, to thoroughly clean the remains of the raw material mass and bio-fertilizers accumulated in the reactor tank when replacing raw materials in the preparation of a new experiment. A wide range of possible types of raw materials (from manure to sawdust) leads to differences in the cost of switching from one experiment to another (for different types of raw materials), which is advisable to take into account when drawing up schedules for experiments.

Let's build a mathematical model for planning experimental work on a biogas plant.

Let's assume that in the planned period of time there came  $n$  requests for experiments:  $A_1, A_2, \dots, A_n$ , and the costs associated with their implementation are:  $c_1, c_2, \dots, c_n$ , while the costs associated with the equipment changeover from the experiment on request  $A_i$  to the experiment on request  $A_j$  are  $d_{ij}$  ( $i, j = 1, 2, \dots, n+1$ ), where  $A_{n+1}$  is the "request" related to bringing the biogas plant to its initial state. The problem is to determine the order of execution of requests, which reaches the minimum total amount of costs.

Let's also introduce the binary indicator variable  $x_{ij}$  by the following formula:

$$x_{ij} = \begin{cases} 1, & \text{if plan contains transition } A_i \rightarrow A_j \\ 0, & \text{in the contrary case} \end{cases}$$

$$(i, j = 1, 2, \dots, n+1; i \neq j).$$

Then the total cost of conducting experiments (taking into account the equipment changeover) will be represented by the target function:

$$F = (\sum_{i=1}^n c_i) + \sum_{i=1}^{n+1} \sum_{j=1, j \neq i}^{n+1} d_{ij} x_{ij}.$$

Since the expression in parentheses that is included in the total cost formula is a constant, the optimization problem is reduced to minimizing the cost of reconfiguring equipment of the biogas plant:

$$f = \sum_{i=1}^{n+1} \sum_{j=1, j \neq i}^{n+1} d_{ij} x_{ij} \rightarrow \min$$

with restrictions on the type of one-time condition of previous request:

$$\sum_{j=1, j \neq i}^{n+1} x_{ij} = 1, \quad (i=1, 2, \dots, n+1)$$

and one-time condition of subsequent request:

$$\sum_{i=1, i \neq j}^{n+1} x_{ij} = 1, \quad (j=1, 2, \dots, n+1).$$

Since the content statement of the considered problem can be attributed to the class of traveling salesman problems (Miller–Tucker–Zemlin formulation) [4], the constructed system of restrictions is naturally supplemented by conditions prohibiting the existence of subcycles:

$$u_i - u_j + (n+1)x_{ij} \leq n, \quad (i, j=2, 3, \dots, n+1; i \neq j),$$

$$u_i \in Z, \quad 0 \leq u_i \leq n, \quad (i=2, 3, \dots, n+1)$$

where integralness and nonnegativity conditions are imposed on auxiliary  $u_i$  variables.

The constructed statement of the optimization problem contains the  $d_{ij}$  parameters included in the target function, which cannot be directly solved without preliminary defining them. We assume that these parameters can take values in the range from 0 to 1 and are related to the characteristics of  $cf_{ij}$  (financial costs when changing equipment from the  $A_i$  request experiment to the  $A_j$  request experiment) and  $ct_{ij}$  (the corresponding time spent).

We assume that in accordance with the concept of a linguistic variable [5,6], the considered characteristics have not only numerical values measured in the corresponding ranges:

$$0 \leq d_{ij} \leq 1, \quad 0 \leq cf_{ij} \leq V_f, \quad 0 \leq ct_{ij} \leq V_t$$

$$i, j = 1, 2, \dots, n+1, \quad i \neq j,$$

but also verbal values from the term-set  $\{low, medium, high\}$ . To build relationships between numerical and verbal values of linguistic variables, expert technologies are used to solve non-standard problems with a high level of uncertainty [7], which is typical of the considered subject area. Transition from the numeric values of the variables  $cf_{ij}$  and  $ct_{ij}$  to the numeric value of the variable  $d_{ij}$  in the fuzzy inference procedure includes the following steps:

1. Fuzzification: transition to verbal values of variables  $cf_{ij}$ ,  $ct_{ij}$  with determination by experts (in the range from 0 to 1) of degrees of correspondence of numerical values of these variables to verbal values of *low*, *medium*, *high*:

$$0 \leq \mu(cf_{ij}, low), \mu(cf_{ij}, medium), \mu(cf_{ij}, high), \mu(ct_{ij}, low), \mu(ct_{ij}, medium), \mu(ct_{ij}, high) \leq 1$$

$$i, j = 1, 2, \dots, n+1, \quad i \neq j.$$

2. Logical conclusion: the transition from the verbal values of the variables  $cf_{ij}$ ,  $ct_{ij}$  to the verbal value of the variable  $d_{ij}$  (determination of the degrees of correspondence  $\mu(d_{ij}, low)$ ,  $\mu(d_{ij}, medium)$ ,  $\mu(d_{ij}, high)$ ) based on a system of  $n(n+1)$  fuzzy production rules in the form:

$$R_{ij}(r_{ij}): \text{if } (cf_{ij} - low, medium, high) \ \& \ (ct_{ij} - low, medium, high) \ \text{then } (d_{ij} - low, medium, high)$$

$$i, j = 1, 2, \dots, n+1, \quad i \neq j$$

and the use of Mamdani algorithm [8]. Rules  $R_{ij}$  and degrees of their reliability  $r_{ij}$  ( $i, j = 1, 2, \dots, n+1$ ;

$i \neq j$ ) can be set by experts basing on their experience in organizing experiments at a biogas plant or built using machine learning methods on the base of training examples ([9]).

3. Defussification: the transition from the verbal values of the variables  $d_{ij}$  with the degrees of correspondence defined in the previous stage  $\mu(d_{ij}, low)$ ,  $\mu(d_{ij}, medium)$ ,  $\mu(d_{ij}, high)$  to the numeric value of the variables  $d_{ij}$ .

To solve the constructed optimization problem, both general methods of mixed integer linear programming (branch-and-cut algorithm, cutting-plane method and etc. [4]) and specialized algorithms (for example, [10-12]) can be used. However, in the case of additional restrictions and a large number of applications, it is advisable to use heuristic evolutionary approaches (in particular, using the approaches proposed in [13,14]).

### 3. Conclusion

The widespread use of knowledge-intensive agro-industrial technologies leads to the fact that experimental research is actually integrated into the production process as a mandatory component. Thus, the planning of scientific activities aimed at improving technological processes in the framework of bioenergy in the agro-industrial complex has practical significance.

The paper presents a mathematical formulation of the problem of minimizing costs when performing experiments on a biogas plant. We propose an approach based on the use of expert technologies and artificial intelligence methods (the theory of linguistic variable, fuzzy production model of knowledge and fuzzy logical inference) to determine the input parameters (coefficients of the objective function) of the problem. Methods for solving the problem are proposed, ranging from traditional methods of discrete linear programming to heuristic evolutionary methods used for solving large-dimensional problems (in the case of planning a large number of experiments).

It should be noted that the scientifically based organization of experimental research, of course, is not reduced to minimizing the cost of conducting them and should be based on a multi-criteria expert evaluation of the effectiveness of scientific activities.

### 4. Acknowledgments

The reported study was funded by RFBR and the Government of the Belgorod Region, project number 18-47-310008.

### References

- [1] Sunggyu L S and Shah Y T 2012 *Biofuels and bioenergy: processes and technologies* (New York: CRC Press)
- [2] Wellinger A, Murphy J and Baxter D 2013 *The biogas handbook: science, production and applications* (Cambridge: Woodhead Publishing)
- [3] Baltrenas P and Baltrenaite E 2018 *Small bioreactors for management of biodegradable waste* (Cham, Sitzerland: Springer International Publishing)
- [4] Rosen K H 2012 *Discrete mathematics and its applications* (New York: McGraw-Hill Publishing)
- [5] Zadeh L A 1975 *Information Sciences* **1** 119-249
- [6] Zadeh L A 2001 *News of Artificial Intelligence* **2-3** 7
- [7] Naydis O A, Naydis I O 2018 *Azimuth of Scientific Research: Economics and Administration* **7(3)** 206-209
- [8] Mamdani E H 1974 *Proceedings of the Institution of Electrical Engineers* **121(12)** 1585–1588
- [9] Wang L X, Mendel J M 1992 *IEEE Transactions on Systems, Man and Cybernetics* **22(6)** 1414-1427
- [10] Cook W J *In pursuit of the traveling salesman: mathematics at the limits of computation.* (Princeton: Princeton University Press)
- [11] Karpinski M, Lampis M and Schmied R 2015 *Journal of Computer and System Sciences* **81 (8)** 1665–1677
- [12] Steinerberger S 2015 *Advances in Applied Probability* **47** 27–36
- [13] Petrosov D A, Lomazov V A, Dobrunova A I, Matorin S I and Lomazova V I 2015 *Biosciences*

*Biotechnology Research Asia* **12(2)** 1767-1775

[14] Petrosov D A, Lomazov V A, Dobrunova A I, Matorin S I and Lomazova V I 2015 *Biosciences Biotechnology Research Asia* **12(3)** 2971-2981