Optimization of organic fertilizers production technology for fractional separation of biodegradable organic waste

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Abstract. The article deals with the technology of reagent treatment of biodegradable organic waste of livestock complexes for the production of organomineral fertilizers. The main regularities of the process of separation into liquid and solid fractions using oxalic acid are determined and analyzed; optimal doses of reagents; dependences of changes in the properties of the fraction at various stages of processing with calcium carbide sludge, comparing them with the indicators obtained using lime milk, superphosphate and phosphogypsum. An optimization model of the reagent process has been created to determine the best conditions for biogenic separation.

1. Introduction
Biodegradable organic waste containing biogenic elements in high concentrations can be a raw material for the production of organic fertilizers. The relevance of using biodegradable organic waste from pig farms is due to their special properties. Organic liquid waste is used as a universal organic fertilizer [1,2] in the form of a suspension, which is a dispersed mixture of an water solution of mineral salts and organic compounds, and solid particles of excrement, feed and a certain amount of mineral inclusions.

According to their chemical properties, these wastes are colloidal solutions, and the dry matter contained in them can only be isolated of using special separation methods [3-5].

For irrigation of agricultural land, biodegradable organic waste containing valuable components - N, P,K [6-8], is suitable only after reagent treatment.

Organic liquid waste consists of a liquid fraction, which has a high fertilizing value and can be used for surface irrigation by sprinkling, and sediment of organic-mineral fertilizer, the use of which is particularly effective on acidic soils [9]. A small number of reagents for destabilizing the colloid system of biodegradable organic waste should be included among the unsolved problems in this field.

Developing a technology for processing biodegradable organic waste, the main concept of the authors is the usage of organic acid as an acidifying reagent, used for the first time instead of previously used superphosphate and phosphogypsum. [10]. The usage of organic acids in the technology of processing organic waste is poorly studied and in the modern scientific literature is represented by a small number of publications.

There is no data in the publication about the usage of oxalic acid as a reagent for the treatment of biodegradable organic waste. Most of the experimental research is devoted to the study of liquid waste’s fractionation of mechanism, this topic was studied by native and foreign scientists Bondarenko a.m.,
Reagent fractionation with using mineral fertilizers by a non-destructive method that allows keeping and increasing biogenic elements [10, 11]. In this case, water is used twice, at first is for self-melting manure, and after reagent separation is for irrigation of the agriculture.

Purpose of the study. Purpose of the study is optimization of parameters of environmentally friendly technology for the process of reagent treatment of liquid waste from pig farms with the replacement of a neutralizing superphosphate reagent, which is not previously studied on this side reagent.

Among these tasks were: to study the main dependencies of the separation into fractions of a complex colloid system of liquid waste from pig farms; to determine the optimal doses of reagents, the impact of mixing time, and their optimization depending on the volume of processed waste.

Objects, materials and methods. There are statistical processing with obtaining regression dependencies [18–20], and optimization in Matlab by the method of sequential quadratic programming.

Research was conducted on the basis of M.I. Platov South-Russian State Polytechnic University. The object of the study was the liquid waste of the pig farm of Batayskoye CJSC in the Rostov Region, with a capacity of 30,000 pigs and a liquid waste flow rate of 150 m$^3$/day.

When conducting studies to determine the optimal parameters of the process of separating the liquid waste of pig farms into fractions, standard cylinders with a volume of 1 dm$^3$ were used. Before the test, the liquid waste was settled for 1 hour, then it was filtered through sieves with sizes of holes 3-5 mm. To determine the temperature $t_p$ and pH of liquid wastes an I-160MI ionomer with an ES-10603/7 K80.7 electrode was used. Electrodes for measuring hydrogen ions were prepared according to the instructions of the ionomers. Investigated the liquid waste of the pig farm to determine their dry matter content [21]. Used a drying cabinet with a heating temperature of 105 °C, laboratory balance 4 accuracy classes.

The optimal dose of the suspension of oxalic acid for the treatment of liquid waste was estimated by the fractionation effect. For this, in 5 identical samples, a suspension of defecation lime in an amount of 2 g / dm$^3$ in active CaO was added at the first stage. In this case, the pH value in each sample was determined; after fixing the time of intensive $t_p$ mixing at this dose of defecation lime suspension, the pH value increased to 12.

At the next stage, an acidifying reagent-suspension of oxalic acid was introduced with a concentration of $C_a \in \left[0.2; 2\right]$ g / dm$^3$. For this, various doses of a 10% suspension of oxalic acid were introduced into the test samples: 0,2; 0,4; 0,6; 0,8; 1; 1,1; 1,2; 1,3; 1,4; 1,5; 1,6; 1,7; 1,8; 1,9; and 2 g / dm$^3$ with stirring for $t_p \in \left[1; 5\right]$ min, thereby lowering the pH to 6,5-8,5. After gravitational sedimentation, the mixture was divided into a transparent liquid fraction and sediment - organic-mineral fertilizer.

The scheme which used for the utilization of biodegradable organic waste using defecation lime of oxalic acid [10] is represented on figure 1:

Concentrated liquid waste flows by gravity from the pig holding rooms (K) to the grids (1), where large undissolved impurities are retained. Further, the liquid waste flows through the pipeline to the settling tank-flow averager (2), which provides for their 2-hour being, during which there is a natural separation into liquid and solid fractions.

Both fractions are fed to the pumping station and pumped by separate pumps (3) to the subsequent structures. The liquid phase of the concentrated waste is fed to the mixers (5), where here are from the reagent farm (4.1 and 4.2) that move a suspension of calcium carbide sludge and a solution of oxalic acid.

Then the mixture of the liquid phase and reagents falls into a vertical settling tank with a conical bottom (6). Here takes place the main reagent separation for 2 hours into liquid and solid fractions. From the sump, 10% of the sediment is returned to the mixer by the pump (7) in order to save reagents. At the same time, the liquid phase and solid fraction from the sump enter separate storage units (8, 9). The solid fraction accumulator is fed with raw sediment formed in the flow-averaging sump.

Further, the sediment is fed to deworming facilities (11), then part of it (in winter) goes to the storage of decontaminated sediment (13), and the rest is used for fertilizing irrigation fields (14).
One of the most important processes of the technological scheme (figure 1) is the separation of liquid and solid fractions of organic waste.

To determine the optimal parameters of technological processes occurring in the settling tank 6, which is added from the mixer 5 processed biological waste, the intensification of separation processes that occur under the action of defecation lime (4.1), and stabilization under the action of oxalic acid (4.2), laboratory work was carried out with relative inaccuracy $\delta[1;3]$.

**Figure 1.** Technological scheme for utilization of biodegradable organic waste using defecation lime and oxalic acid:

K – meat cluster; 1 – grids; 2 - receiving tank–averager; 3 – pumps for pumping of liquid phase and fresh sediment; 4.1, 4.2 – chemical farming; 5 – mixer; 6 - settling tank; 7 –pump draught; 8 - the drive of the liquid phase; 9 - sludge storage; 10 - thickener; 11 - structures of dehelmintization; 12 – a tank of fresh water; 13-drive decontaminated sediment in winter; 14 - sections of irrigation; 15- hydrowashing products of meat cluster; 16 - fresh sediment; 17 - liquid phase of hydrowashing products; 18 - sediment after chemical treatment; 19 – fresh water; 20-liquid phase after dilution; 21-decontaminated sediment.
2. Results and discussions

Based on the results of regression analysis of experimental studies, graphical figure 2 and polynomial dependences (1) of the separation efficiency on 3 factors of mixing time \( t \), initial pH value, and the dose of lime (alkali) \( C \) were applied.

The research results allowed us to establish that the optimal dose of lime is 2 g / dm\(^3\) for active CaO.

Besides the separation efficiency, one of the main factors is the stabilization or adjustment of the sediment by pH. When processing experimental data, the graphical (figure 2) and empirical dependences (2) changes were obtained.

Since the initial temperature of liquid waste has the least impact on the settling process in the selected temperature range and cannot be regulated in the process rate.

\[
\begin{align*}
\mathcal{E} &= 148,0 + 5,828 \cdot t - 27,271 \cdot \text{pH} - 11,437 \cdot C^2 - 2,114 \cdot t^2 + 1,356(\text{pH})^2 + \\
&+ 1,262 \cdot C \cdot t + 4,193 \cdot C \cdot \text{pH} + 0,587 \cdot t \cdot \text{pH} \\
\text{pH}_s &= 14.965 - 0.456 \cdot t_p - 1.432 \cdot \text{pH} + 3,240 \cdot C_{\text{acid}}^2 - 0.036 \cdot t_p^2 - 0.121 \cdot 10^3 \cdot \text{pH}^2 - \\
&- 1.054 \cdot C_{\text{acid}} \cdot t_p - 0.911 \cdot C_{\text{acid}} \cdot \text{pH} + 0,208 \cdot t_p \cdot \text{pH},
\end{align*}
\]

For the optimization process, we used the conjugated gradient method for two-factor dependencies (1) and (2). This method refers to an iterative numerical method (first order) for solving optimization problems, which allows us to determine the extremum of the objective function presented below:

\[
CF(C, C_{\text{acid}}, \text{pH}) = \alpha_1 \left( 1 - \frac{\mathcal{E}(C, t_p, \text{pH})}{100} \right) + \alpha_2 \left( \frac{\text{pH}_s(C_{\text{acid}}, t_p, \text{pH})}{100} \right),
\]
which $\alpha_1$, $\alpha_2$ - accordingly the weight coefficients accord to the efficiency of separating the dose of alkali, g / dm$^3$ and the initial pH value.

Figure 3. Dependence of adjustment, pH after acid introduction: 1 - 0.2 g/dm$^3$; 2 - 1.1 g/dm$^3$; 3 - 2.0 g/dm$^3$.

For searching the minimum value, we use the function $\text{Minimize}(CF, C, t_p)$ of Mathcad 15. The optimization results are shown in table 1.

**Table 1.** Results of optimization of the studied reagent method.

| №  | The weight coefficients | The optimization parameters | pH, % |
|----|------------------------|---------------------------|-------|
| 1  | 0.0                    | 56.515                    | 5.999 |
| 2  | 0.1                    | 79.000                    | 6.200 |
| 3  | 0.2                    | 84.000                    | 6.370 |
| 4  | 0.3                    | 87.000                    | 6.650 |
| 5  | 0.4                    | 90.000                    | 6.710 |
| 6  | 0.5                    | 95.0                      | 6.9   |
| 7  | 0.6                    | 99.000                    | 7.00  |

Upon the results of the optimization analysis, the best solution is to achieve the separation efficiency and the initial pH value at weight coefficients, respectively, and, according to which you can assign proportions for the dose of acid and alkali, and set the mixing time.

During technical-economic analysis of the equipment cost of and reagents for a range of expenses from 1 to 20 m$^3$/day taking into account the optimal choices of the number of cycles (5 cycles per day) downloads per day, characteristics of the model vertical settling tank 6 by the technological scheme (figure 1) was built graphic dependences (figure 4).
Figure 4. Dependence of productivity on: a-cost of equipment; b-cost of reagents.

Out of the cost of equipment and reagents, the most rational technical solution is to use this technology for processing small volumes up to 10 m$^3$/day.

Conclusions
Determined empirical dependences (1) and (2), also, optimized by the conjugated gradient method efficiency of waste separation time and initial pH values depending on the dose of alkali, stirring time and dose of acid to stabilize, allowing determining their best proportion.

Determined that the most effective range of the proposed technological scheme is the flow rate from 1 to 10 m$^3$/day (figure 1).

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