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# MODELING OF COAGULATION PROCESSES IN THE REAGENT SEPARATION OF AGRICULTURAL WASTE

Research article

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**Abstract**

When producing fertilizers from liquid waste from pig farms, reagent fractionation processes are carried out, during which particles become larger and fall out as sediment as a result of settling. Effective coagulation time varies depending on environmental conditions, reagent concentrations and other factors. The task is to determine the state of the system depending on time at different densities of liquid waste, as well as to determine the coagulation rate. The article discusses methods for describing the processes of coagulation of monodisperse media during the processing of liquid waste from pig farms in order to obtain organomineral fertilizer. Chemical coagulation is a widely used and easily applicable method for treating such wastes. However, this method requires optimization to improve coagulation efficiency while minimizing the use of chemicals. To describe the processes occurring, Smoluchovski equations were used in a spatially homogeneous case. The individual and combined influence of independent variables on the desired response parameters were used to construct a mathematical model of the rapid coagulation of liquid waste from pig farms after reagent treatment. The data obtained can be used to determine the rate of coagulation at various time intervals from its beginning, however, it is necessary to take into account the composition of liquid waste and the physical mechanisms causing coagulation, and the description of the system should be considered in the form of a system of kinetic differential equations for a more accurate determination of the core.

**Keywords:** liquid waste, pig complex, coagulation, reagent fractionation, mathematical description, organomineral fertilizer.

# МОДЕЛИРОВАНИЕ ПРОЦЕССОВ КОАГУЛЯЦИИ ПРИ РЕАГЕНТНОМ РАЗДЕЛЕНИИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ОТХОДОВ

Научная статья

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**Аннотация**

При производстве удобрений из жидких отходов свинокомплексов проводят процессы реагентного фракционирования, при которых происходит укрупнение частиц и выпадение их в виде осадка в результате отстаивания. Время эффективной коагуляции варьируется в зависимости от условий окружающей среды, концентрации реагентов и прочих факторов. Задачей ставится определение состояния системы в зависимости от времени при различной плотности жидких отходов, а также определение скорости коагуляции. В статье рассмотрены методы описания процессов коагуляции монодисперсных сред при переработке жидких отходов свинокомплексов с целью получения органоминерального удобрения. Химическая коагуляция является широко используемым и легко применимым методом обработки таких отходов. Однако этот метод требует оптимизации для повышения эффективности коагуляции при минимизации использования химических веществ. Для описания происходящих процессов использовались уравнения Смолуховского в пространственно-однородном случае. Индивидуальное и совокупное влияние независимых переменных на желаемые параметры ответа применялись для построения математической модели быстрой коагуляции жидких отходов свинокомплексов после реагентной обработки. Полученные данные можно использовать для определения скорости коагуляции в различные промежутки времени от ее начала, однако необходимо учитывать состав жидких отходов и физические механизмы, вызывающие коагуляцию, описание же системы рассмотреть в виде системы кинетических дифференциальных уравнений, для более точного определения ядра.

**Ключевые слова:** жидкие отходы, свинокомплекс, коагуляция, реагентное фракционирование, математическое описание, органоминеральное удобрение.

## Introduction

Liquid waste resulting from intensive livestock farming has a negative impact on the environment. Nitrogen and phosphorus compounds in waste from pig farms pollute the soil and water bodies. Stored liquid waste produces odor, primarily due to anaerobic decomposition of proteins. Pig farm waste is a mixture of feces, urine and water. Before they can be processed and disposed of, waste must be separated into solid and liquid fractions. With proper processing, these wastes become suitable for application to the soil as fertilizers [1], [2]. Extensive research has been conducted to evaluate the performance of various separation technologies in laboratory or pilot scale conditions, only a few of which are capable of achieving complete separation. Many methods for separating liquid waste from pig farms affect the nitrogen characteristics of the resulting liquid and solid fractions, which can alter its potential availability to plants. The simplest technology, physical separation, can remove up to 80% of the total solids. Modern separation processes have some limitations, such as high investment and processing costs. For a rational choice of manure treatment method, scientifically based results on the separation efficiency and fertilizing value of the resulting products are necessary [3]. When mechanically separating liquid waste from pig farms, fine particles are degraded more quickly than large particles, and most of the recovered carbon, protein and nutrients are contained in the fine particles. Because these compounds are odor sources and carriers of organic nitrogen and phosphorus, it is recommended that solid-liquid separation processes be implemented to remove both large waste particles and particles smaller than 0.25 mm to significantly reduce both odor generation and nutrient content. Chemicals may be required to remove fine particles and dissolved phosphorus. Separation using physicochemical treatment followed by coagulation and sedimentation has become widespread [4], [5], [6]. Chemical coagulation is a widely used and easily applicable method for treating such wastes. However, this method requires optimization to improve coagulation efficiency while minimizing the use of chemicals.

**Research methods and principles**

Mathematical analysis is empirical modeling that can be used to develop relationships between process factors and experimental results. Mathematical models with fast analytical methods allow rapid prediction of decomposition rate constants and are very useful for studying the coagulation process of liquid waste from pig farms.

Various articles by domestic and foreign authors examine in detail the theoretical foundations of coagulation. Mathematical models have been developed that describe the state of monodisperse media during coagulation in the air and liquid phases, which are based on the works of Smoluchowski [7], [8], [9]. For example, A.M. Shterenberg and D.A. Filippov model coagulation processes based on the use of systems of kinetic differential nonlinear equations, and V.A. Galkin examined in detail the cases of solutions to the Smoluchowski equation under various initial conditions. Reihard Lang and Nguen Xuan Xanh in their work “Smoluchovski's Theory of Coagulation in Colloids Holds Rigorously in the Boltzmann-Grad-Limit” formulated and proved several key theorems that provide an in-depth understanding of the behavior of a dispersed system during coagulation. All of the above works are based on the basic theory of DLFO (aggregative stability of lyophobic disperse systems).

However, none of the modern works has studied in detail the behavior of polydisperse systems of liquid fractionated organic waste, consisting of substances in different concentrations during settling and mixing. The study of coagulation processes in such systems will help to describe in more detail the behavior of particles and theoretically determine the state of the system at different times under different initial conditions.

**Main results**

To describe the processes occurring, we started from the Smoluchovski equation in a spatially homogeneous case. The individual and combined effects of the independent variables on the desired response parameters were used to construct a mathematical model. We will assume that all colliding particles will become larger. In this case, the Smoluchovski equation will take the following form:

$$u(x,t) = \frac{1}{\left(1+\frac{t}{2}\right)^2} \exp\left[-\frac{x}{1+\frac{t}{2}}\right] \quad (1)$$

However, if a constant source of particles is present in the system, with the intensity of coagulation being maintained, then the following Cauchy problem will have the form:

$$\frac{\partial\varphi(m,t)}{\partial t} = -\varphi(m,t)\int_0^\infty \varphi\,(m_1,t)\,dm_1 + q\,(m_1) \quad (2)$$

The absence of a solution in this case was proven in [7]. In what follows, we will assume that the system has a finite number of particles N and tends to enlarge all particles inside the system with further precipitation. There are other cases in which there will be solutions, for example, in the case of a limited kernel (a function that is determined by a specific type of physical mechanism causing coagulation φ(t)), the existence of a classical solution was proven in [10], and provided that the kernel increases no faster than linear in its arguments in [9], [10], [11].

Let us consider the classical case and compare it with experimental data. Let us denote by $N_m$ the concentration of aggregates containing m particles: $\varphi(m,0) = \varphi_0 = 0.$

For rapid coagulation we can assume the following form of the equation:

$$\frac{dN_m}{dt} = \frac{1}{2}\sum_{i=1}^{m-1} \varphi_0 n_i n_{m-1} - \sum_{j=1}^{\infty} \varphi_0 n_m n_j \quad (3)$$

It is important to note that the core is stationary and does not depend on the mass and size of the particles. The exact solution of the system of equations will have the following form:

$$\varphi_0 = \frac{8k_bT}{3\eta} \quad (4)$$

where $\tau_0$ is the time of half coagulation according to Smoluchovski.

$$N_m = \frac{n_0\left(\frac{t}{\tau_0}\right)^{m-1}}{\left(1+\frac{t}{\tau_0}\right)^{m+1}} \quad (5)$$

The values of experimental and calculated coagulation rates at various densities of liquid waste are presented in Table 1.

Based on experimental data [1], [2], we will plot the dependence of particle concentration on time and density of liquid waste. The calculation results are shown in Figure 1.

Table 1 - Values of experimental and calculated coagulation rates at different densities of liquid waste

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| Density liquid waste, mg/m$^3$ | Coagulation rate after time t from the beginning of coagulation | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1min ($10^{13}$) | | 2min ($10^{12}$) | | 4min ($10^{11}$) | | 6min($10^{11}$) | | 8min($10^{11}$) | | 10min($10^{10}$) | |
| | experiment | calculated | experiment | calculated | experiment | calculated | experiment | calculated | experiment | calculated | experiment | calculated |
| 1034.3 | 0.89 | 1.05 | 2.94 | 2.63 | 6.57 | 6.58 | 3.25 | 2.83 | 1.46 | 1.59 | 10.12 | 9.86 |
| 1038.4 | 1.26 | 1.47 | 4.09 | 3.68 | 10.36 | 9.21 | 4.59 | 3.96 | 2.12 | 2.23 | 15.16 | 14.2 |
| 1042.4 | 1.99 | 2.37 | 6.46 | 5.93 | 14.06 | 14.82 | 7.71 | 6.59 | 3.42 | 3.59 | 23.15 | 22.98 |
| 1046.4 | 4.38 | 5.18 | 14.08 | 12.94 | 32.25 | 32.37 | 16.69 | 14.39 | 8.01 | 8.09 | 51.03 | 50.27 |
| 1050.4 | 7.06 | 8.47 | 18.74 | 21.17 | 51.47 | 52.91 | 25.89 | 23.52 | 13.01 | 13.23 | 85.28 | 84.67 |

The data obtained can be used to determine the rate of coagulation at various time intervals from its onset.

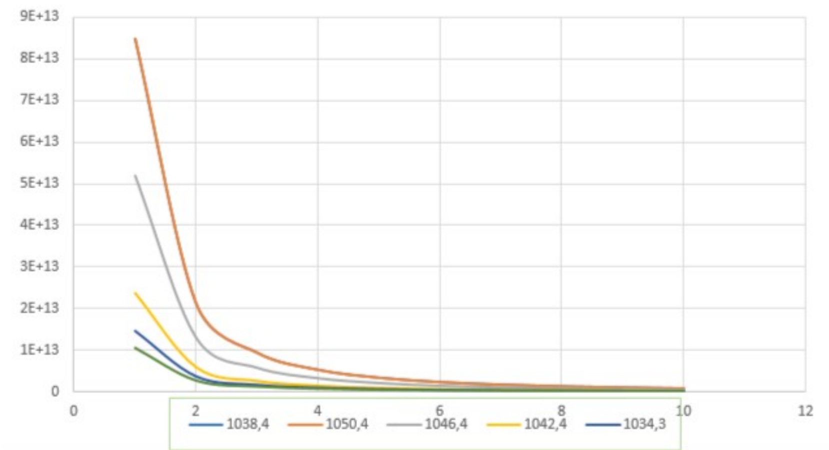


Figure 1 - Results of theoretical calculation of the coagulation rate of liquid waste depending on their density

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The results obtained differ significantly from the experimental data, primarily due to the lack of consideration of the mechanisms of slowing down coagulation, as well as the interaction between various compounds of the useful components of nitrogen, potassium and phosphorus. Thus, at a density of 1050.4 mg/m3 2 minutes after the start of coagulation, the calculated coagulation rate is 1.2 times higher than the experimental one obtained in laboratory conditions. And after 6 minutes, the same speed is 1.1 times lower than the experimental one. First of all, it is necessary to clarify the composition of liquid waste and the physical mechanisms that cause coagulation, and consider the description of the system in the form of a system of kinetic differential equations for a more accurate determination of the core. Conclusions on the theory of coagulation are presented within the framework of the DLFO theory, where it is possible to clarify the interaction of molecules and calculate the interaction energy in potential minima and maxima.

**Conclusion**

A mathematical model built on the basis of the classical Smoluchowski equation allows one to calculate the coagulation rate in a system with a finite number of particles and a coagulation efficiency equal to 1, i.e. where all collisions lead to particle enlargement. The convergence of the obtained calculated results with the experimental ones is 80-85%. However, in reality, physical mechanisms arise that reduce the efficiency of coagulation due to the emergence of potential barriers during the interaction of particles. These factors lead to the need to complicate the mathematical model and construct a system of differential equations that take into account the efficiency of coagulation, particle size, physical mechanisms and experimental conditions. In subsequent studies, it is planned to construct a mathematical model of the entire process of reagent fractionation of liquid waste from a pig farm, including the described model of the coagulation stage, taking into account the above factors.

**Конфликт интересов**

Не указан.

**Conflict of Interest**

None declared.

**Рецензия**

Все статьи проходят рецензирование. Но рецензент или автор статьи предпочли не публиковать рецензию к этой статье в открытом доступе. Рецензия может быть предоставлена компетентным органам по запросу.

**Review**

All articles are peer-reviewed. But the reviewer or the author of the article chose not to publish a review of this article in the public domain. The review can be provided to the competent authorities upon request.

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