SATBAYEV UNIVERSITY

Computing & Engineering

Volume 1 (2023), Issue 1, 41-46

https://doi.org/10.51301/ce.2023.i1.08

Development of an optimal control system for the drying tower of the sodium tripolyphosphate production process

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Abstract. Sodium tripolyphosphate ($Na_5P_3O_{10}$) is an important chemical compound widely used in various industries, including food, chemical and pharmaceutical. Used as a stabilizer, leavening agent and water softener. The development of an effective control system for the extraction process of sodium tripolyphosphate is an urgent task to improve production efficiency and ensure product quality. Today's industry is increasingly focusing on developing and optimizing chemical extraction processes to improve efficiency and reduce costs. One such item is food, pharmaceuticals, glass, etc. Sodium tripolyphosphate, which is widely used in various industries. The development of a control system for the sodium tripolyphosphate extraction process is of great importance for optimizing and increasing the efficiency of this process. The relevance of this task is due to the fact that the process of producing sodium tripolyphosphate has certain difficulties and depends on temperature, pressure, ratio of reagents, etc. This is due to the fact that it is necessary to control and adjust various parameters. As a result, an automated model of drying towers was developed to improve efficiency and reduce costs in the sodium tripolyphosphate industry.

Keywords: *automatic control system, extraction process, drying towers, mathematical model.*

1. Introduction

The drying tower is a vertical cylindrical device with a conical bottom. The top of the tower is equipped with an explosion valve and two mixing baffles that mix two heat flows: the first from the turbocalciner and the second from the combustion of natural gas in the upper burner.

First of all, it should be noted that none of the installations of the drying and heating shop has an optimal process control system, which is closely related to the lack of an adequate mathematical model of these processes.

The quality of SPTP increases by 10-15% with the introduction of an optimal control system in the drying tower of the sodium tripolyphosphate production process. Moreover, the process is carried out with minimal fuel consumption and low consumption of finished products [4].

2. Materials and methods

In modern industry, more and more attention is paid to the development and optimization of chemical extraction processes in order to increase efficiency and reduce costs. One of these items is food, pharmaceuticals, glass, etc. sodium tripolyphosphate, which is widely used in various industries.

The technological scheme of production of sodium tripolyphosphate using a drying-heating furnace, as well as the device and working principle of this process were studied. The calculation of the material balance has been completed. Based on the results of the calculations, a promising and effective integrated method scheme was selected, which allows to achieve high efficiency.

To achieve this goal, it is necessary to solve the following tasks:

- analysis of existing methods and technologies for obtaining sodium tripolyphosphate;
- research and identification of the main factors affecting the process of obtaining sodium tripolyphosphate;
- creating a mathematical model of the sodium tripolyphosphate production process;
- development of a management algorithm based on a mathematical model and considering the main factors;
- development of software for implementation of management system;
- conducting experiments to check the effectiveness of the developed management system:

It is expected that the results of this work can be used in various fields where it is necessary to obtain sodium tripolyphosphate. Development of management system allows to reduce costs

Sodium tripolyphosphate (sodium tripolyphosphate) production technology is an important process in the chemical industry. Sodium tripolyphosphate is an inorganic compound used in many applications such as the food processing, laundry and metallurgical industries.

The production process of sodium tripolyphosphate begins with the main raw materials - phosphates, for example, rock and bone phosphates. Phosphates usually contain 16-18% tribasic phosphate, which is the main single component for the production of sodium tripolyphosphate.

One of the first steps in the process is to treat the phosphates with a sulfuric acid solution to remove unwanted impurities such as iron and aluminum. The resulting phosphate solution is then filtered to remove phosphate deposits.

After filtration, the phosphate solution is mixed with sodium hydroxide solution, resulting in a white precipitate of sodium tripolyphosphate. The resulting sediments are separated from the liquid through the sedimentation process.

Sodium tripolyphosphate precipitates undergo a drying process that results in a stable material that is easily stored and transported.

The production process of sodium tripolyphosphate usually involves several steps:

Preparation of sodium phosphate: Primary components are phosphoric acid (H_3PO_4) and sodium hydroxide (NaOH). These reagents react in the reactor to form sodium phosphate (Na_3PO_3) and water (H_2O).

$$H_3PO_4 + 3NaOH \rightarrow Na_3PO_4 + 3H_2O \quad (1)$$

Neutralization process: After sodium phosphate is produced, its solution is neutralized by adding an alkali such as sodium hydroxide (NaOH). This leads to the formation of basic sodium phosphate.

$$Na_3PO_4 + NaOH \rightarrow Na_4P_2O_7 + H_2O \quad (2)$$

Precipitation of tripolyphosphate: The resulting basic sodium phosphate ($Na_4P_2O_7$) is further processed to produce sodium tripolyphosphate. The basic phosphate solution is heated and excess water is removed by evaporation. As a result, a solid precipitate of sodium tripolyphosphate is formed.

$$Na_4P_2O_7 + H_2O \rightarrow Na_5P_3O_{10} \quad (3)$$

Purification and drying: The resulting sodium tripolyphosphate is purified to remove impurities and undesirable compounds. It is then processed to the proper particle size and dried to remove residual moisture.

Packaging and Storage: Purified and dried sodium tripolyphosphate is packaged according to customer requirements and stored in a safe and dry place until use.

The obtained sodium tripolyphosphate has a wide range of applications. In the food industry, it is used as an emulsifier and stabilizer that improves the structure and shelf life of food. In the metallurgical industry, sodium tripolyphosphate is used as an additive to remove rust and increase process productivity. It is also used in the production of detergents to remove grease and prevent scale formation.

The production technology of sodium tripolyphosphate is complex and many factors such as temperature, concentration of reagents and reaction time can affect the final quality of the product. Effective manufacturing technology requires careful control of these factors and continuous process improvement to achieve optimal results.

The melting point is 622°C, in its pure state it is quite stable up to the melting point, when the temperature is further increased, it decomposes into meta and pyrophosphate.

Sodium tripolyphosphate is also soluble in water. Dissolves up to 50 g in 100 ml of water at a temperature of 20°C.

As for the production technology at the sodium tripolyphosphate plant:

The production of sodium tripolyphosphate is a complex chemical process carried out in a factory. These include:

Raw materials: The main raw materials for the production of sodium tripolyphosphate are phosphoric acid (H_3PO_4) and sodium hydroxide (NaOH).

Dosing and mixing: Phosphoric acid and sodium hydroxide are dosed and mixed in special reactors. Control additives and catalysts are added to ensure optimal reaction conditions.

Reaction: In reactors, a reaction takes place between phosphoric acid and sodium hydroxide, resulting in the formation of sodium tripolyphosphate ($Na_5P_3O_{10}$) and water (H_2O). This is an exothermic reaction accompanied by heat release.

Separation and purification: after the completion of the reaction, the resulting mixture passes through special separation units that separate the liquid phase (water) from the solid phase (sodium tripolyphosphate). Purification of sodium tripolyphosphate may involve the use of filtration, drying, and other methods.

Forming and Packaging: After purification, sodium tripolyphosphate can be crushed, graded and packaged according to customer requirements. It usually comes in powder or pellet form.

Quality control: Quality control is carried out at every stage of production to ensure that the product conforms to established standards. This may include analysis of active ingredients, purity tests and physicochemical measurements.

Waste Disposal: The production of sodium tripolyphosphate can generate waste and wastewater. The plant must provide a system for the treatment and disposal of these wastes in accordance with environmental and safety standards.

On an industrial scale, sodium tripolyphosphate is produced from solutions of sodium orthophosphate in a one- or two-step process. In the first version, drying and heating are carried out in the same device, often in a rotary kiln that recycles the product.

The entire sodium tripolyphosphate manufacturing process requires compliance with strict safety and regulatory requirements to ensure high quality products and minimize potential adverse environmental impacts [1].

Sodium tripolyphosphate ($Na_5P_3O_{10}$) is a chemical widely used in various industries such as food processing, laundry, detergents, dishwashing detergents, glass, ceramics and other materials.

Raw materials and reactions

The production of sodium tripolyphosphate is based on the use of phosphoric acid (H_3PO_4) and sodium hydroxide (NaOH) as starting materials. The reaction between phosphoric acid and sodium hydroxide leads to the formation of sodium tripolyphosphate:

$$2NaOH + H_3PO_4 \rightarrow Na_5P_3O_{10} + 3H_2O \quad (4)$$

Production process

The production process of sodium tripolyphosphate can be divided into several main stages:

1. Preparation of the reaction mixture: Phosphoric acid and sodium hydroxide are mixed in a reactor in known proportions. Usually, an excess of sodium hydroxide is used to ensure complete conversion of phosphoric acid.

2. Reaction: The mixture is heated to a certain temperature and kept liquid by mechanical stirring. A chemical reaction occurs between phosphoric acid and sodium hydroxide, resulting in the formation of sodium tripolyphosphate.

3. Cooling and crystallization: After the reaction is completed by cooling the mixture, the obtained sodium

tripolyphosphate comes out of the solution in the form of crystals.

4. Separation and drying: The resulting sodium tripolyphosphate crystals are separated from the solution and subjected to a drying process to remove excess moisture.

Quality and control

Product quality control is an important aspect in the production process of sodium tripolyphosphate. This includes the analysis of the composition of the main substance, the identification of impurities and contaminants, as well as physico-chemical and microbiological tests. Quality control ensures product compliance with established standards and safety requirements [2].

The production of sodium tripolyphosphate is based on the reaction between phosphoric acid and sodium hydroxide. This process includes preparation of the reaction mixture, chemical reaction, cooling and crystallization, separation and drying of the obtained product. Quality control is an important part of production to ensure product compliance with requirements and standards.

Below is detailed information on some of the physicochemical properties of sodium tripolyphosphate:

1. Solubility

Sodium tripolyphosphate is highly soluble in water. Easily dissolves up to 10 g/ml at room temperature. This makes it effective for use in processes that require rapid and complete dissolution of water-soluble components.

2. Chemical stability

Sodium tripolyphosphate is chemically stable under most conditions. It is stable in alkaline solutions and has high thermal stability. But under acidic conditions or at high temperatures, it can decompose into phosphates with a lower oxidation state.

3. pH

Sodium tripolyphosphate is an alkaline compound. Therefore, its solutions have a high pH, typically around 11 in a 1% solution. This property makes it useful in processes where the pH needs to be controlled or maintained, such as detergent production or food stabilization.

4. Formation of complexes

Sodium tripolyphosphate forms complexes with various metal ions, including calcium, magnesium and iron ions. This allows it to be used in processes such as degreasing and defoaming in industrial systems to remove solid deposits and precipitated salts. Hardening properties can also be used to stabilize foods and prevent ingredients from settling or mixing.

5. Source of phosphorus

Sodium tripolyphosphate is a good source of phosphate, which is important in biological processes. Phosphorus is an important element for the growth and development of plants, as well as for the normal functioning of the body. In the food industry, sodium tripolyphosphate can be used as an additive to improve the structure and texture of food products.

6. Form and appearance

Sodium tripolyphosphate appears as colorless or white crystals, usually in powder or granular form. It has a very high density of about 2.5 g/cm³.

The drying tower is a vertical cylindrical device with a conical bottom. The top of the tower is equipped with an explosion valve and two mixing baffles that mix two heat flows: the first from the turbocalciner and the second from the combustion of natural gas in the upper burner.

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The scheme of automatic adjustment of the orthophosphate drying process is as follows (Figure 1).

Various devices are used in raw material drying, especially spread drying towers are considered widespread.

Diffusion drying towers are designed for drying sodium orthophosphate and are designed to reduce moisture content to 1%. The drying tower (9) is a vertical cylindrical apparatus, conical downwards. The upper part of the tower is equipped with an explosion (explosion) valve and two mixing baffles that mix two coolant flows: the first from the turbo calciner and the second from the upper natural gas combustion burner. The upper pressure manifold is located outside the tower under the mixing chamber. Decomposes orthophosphate solution consists of 32 nozzles (10) with a hole diameter of 0.8 mm.

In the nozzle, orthophosphate is distributed and sprayed under a pressure of 9-15 MPa through a pipe drive. Injector burners (8) are located in the tower. Dispersed orthophosphate is dried by burning gas in a burner. Dried orthophosphate is dehydrated and crushed in a drying tower goes down. From here it is sent directly to the turbo calciner (12).

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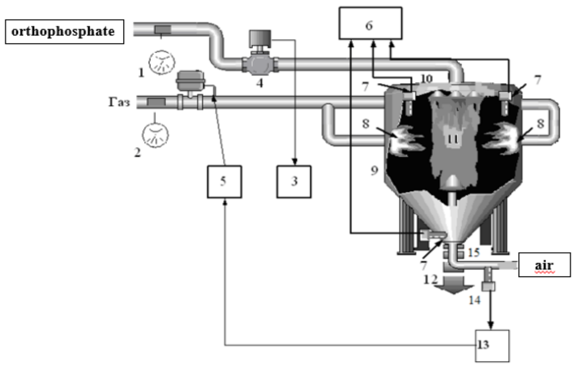

Figure 1. Diagram of automatic adjustment of the orthophosphate drying process

Various devices are used in raw material drying, especially spread drying towers are considered widespread.

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Control of gas and orthophosphate pressure is carried out by manometers 1 and 2. Temperature control is carried out by means of thermocouples (7), whose readings are recorded in a multi-point automatic potentiometer (6) located at different points of the tower. Loss of orthophosphate is measured by an induction flow meter consisting of a sensor (4) and a measuring block (3).

The automatic control system of the process is implemented as follows: the moisture meter measures the moisture content of the dried orthophosphate. Humidity 1%-is lower than, the moisture meter sends a signal to the controller (13). It itself sends a signal to the executive mechanism [1].

3. Results and discussion

A drying tower was considered as an object. The transfer function of the object was given by the second-order aperiodic cut-off equation. This section is expressed by a second-order differential equation:

$$W_0(s) = \frac{1}{6s^2 + 5s + 1} \qquad (5)$$

The task of the designer when choosing the type of regulator should be to provide a quality job of the regulator at minimum cost and maximum reliability. The designer may choose a relay, continuous, or discrete (digital) controller type [3].

To choose the type of regulator and determine its flexibility, you need to know the following:

1. Static and dynamic description of the control object
2. Regulatory quality process requirement
3. Regulator quality indicator for serial regulators
4. Exciting character that affects the regulatory process.

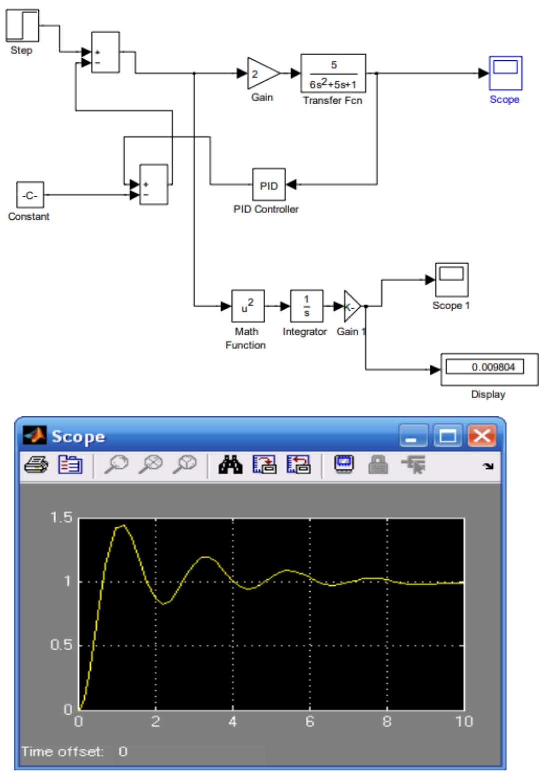

Figure 2. Graph of the automatic regulation system

The dynamic equation of the heat balance in the drying tower:

$$\rho_{ca} \times V_{ca} \times c_{ca} \times \frac{d\theta}{dt} = G_{ca} \times c_{pca} \times \theta_{ca} + G_{bm} \times c_{pca} \times \theta_{ca} - \\ - G_{ca} \times c_{pem} \times \theta_{ca} - G_{cm} \times c_{pem} \times \theta_{cm} - W_m \times r \qquad (6)$$

Where: V_{ca} - is object volume; c - concentrations; G - expenses; θ- temperatures.

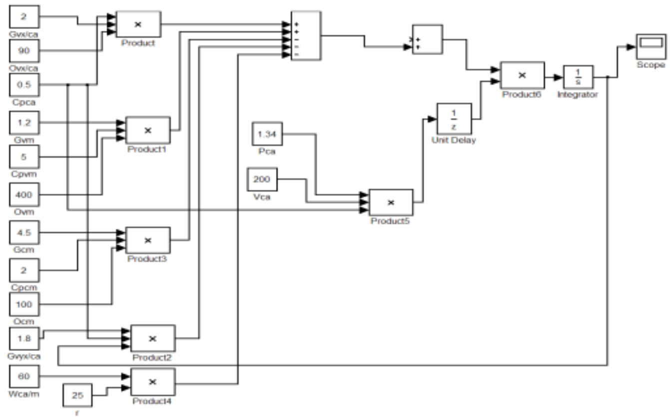

Figure 3. Compilation of the dynamic equation of the heat balance in Simulink

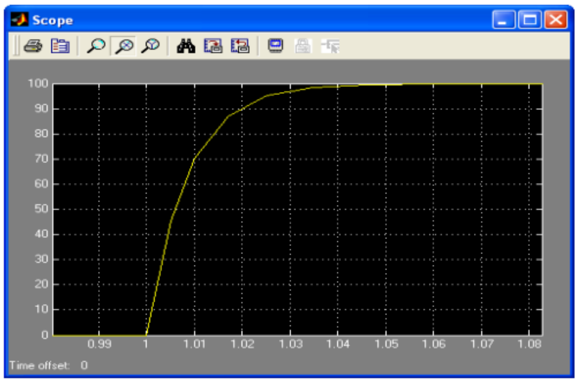

Figure 4. Graph of the dynamic equation of heat balance

The dynamic equation of the material balance depending on the amount of moisture in the product:

$$\rho_{ca} \times V_{cm} \times \frac{d\omega}{dt} = G_{bm} \times \omega_{bm} - G_{cm} \times \omega_{cm} - W_m \qquad (7)$$

Where ω_{cm}, ω_{bm} - material humidity.

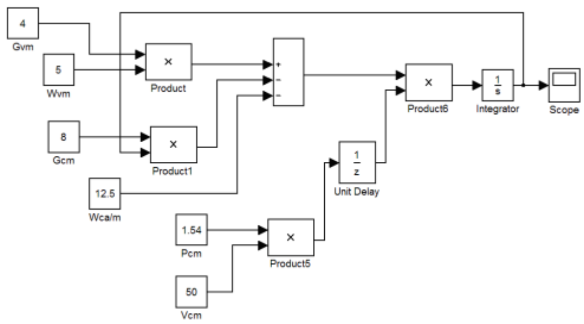

Figure 5. Compilation of the dynamic equation of the material balance in Simulink

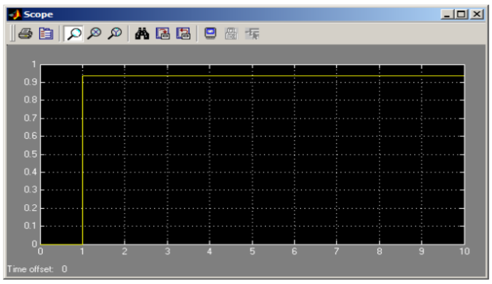

Figure 6. The graph of the dynamic equation of the material balance

Dynamic equation of the material balance in the drying process:

$$\rho_{ca} \times V_{cm} \times \frac{d\omega}{dt} = G_{bm} \times \omega_{bm} + G_{bm} \times \varphi_{ca} - G_{cm} \times \omega_{cm} - G_{ca} \times \varphi_{ca} \quad (8)$$

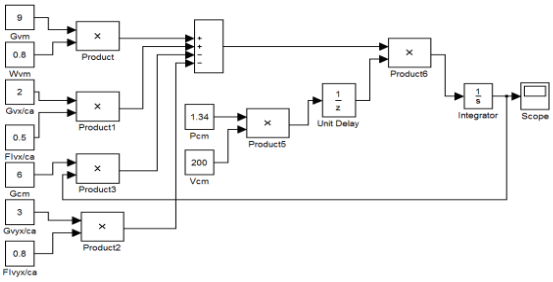

Figure 7. Compilation of the dynamic equation of the material balance in Simulink

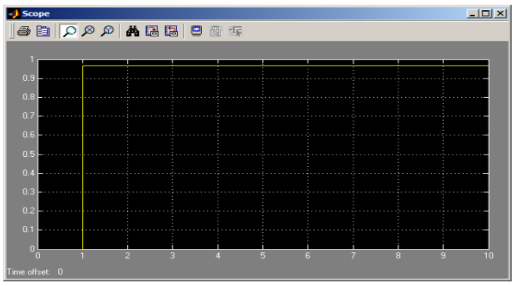

Figure 8. The graph of the dynamic equation of the material balance

It is expected that the results of the work can be used in various fields where it is necessary to obtain sodium tripolyphosphate. Development of a control system reduces costs.

4. Conclusions

Global production of sodium tripolyphosphate will continue to increase until algal blooms become a problem in water bodies. Therefore, saving the world from this problem is the main goal of this project. Russia, China, Kazakhstan: the main producing countries of sodium tripolyphosphate.

In order to optimize the production of sodium tripolyphosphate and improve product quality, a control system is being created that allows for effective monitoring and regulation of the sodium tripolyphosphate production process.

It is expected that the results of this work can be used in various fields where it is necessary to obtain sodium tripolyphosphate. Development of a control system reduces costs.

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Триполифосфат натрий өндіру үрдісіне кептіргіш мұнараға оптималды басқару жүйесін әзірлеу

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Аңдатпа. Бұл мақалада натрий триполифосвтын алудың автоматты басқару және басқару жүйесін әзірлеу процесі қарастырылған. Натрий триполифосфаты ($Na_5P_3O_{10}$) әртүрлі салаларда, соның ішінде тамақ, химия және фармацевтика салаларында кеңінен қолданылатын маңызды химиялық қосылыс. Тұрақтандырғыш, қопсытқыш және су жұмсартқыш ретінде қолданылады. Натрий триполифосфатының экстракция процесін бақылаудың тиімді жүйесін жасау өндіріс тиімділігін арттыру және өнім сапасын қамтамасыз етудің кезек күттірмейтін міндеті болып табылады. Осы процесті оңтайландыру және тиімділігін арттыру үшін натрий триполифосфатының экстракция процесін басқару жүйесін жасаудың үлкен маңызы бар. Бұл мәселенің өзектілігі натрий триполифосфатын алу процесінің белгілі бір қиындықтарға ие болуымен және температураға, қысымға, реагенттер қатынасына және т.б. тәуелді болуына байланысты.Бұл әртүрлі параметрлерді бақылау және реттеу қажеттігіне байланысты. Нәтижесінде натрий триполифосфат өнеркәсібінің тиімділікті арттыру және шығындарды азайту үшін кептіру мұнараларының автоматтандырылған моделі әзірленді.

Негізгі сөздер: *автоматты басқару жүйесі, экстракция процесі, кептіру мұнаралары, математикалық модель*.

Разработка оптимальной системы управления сушильной башней процесса производства триполифосфата натрия

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Аннотация. В данной статье рассмотрен процесс разработки автоматической системы управления и контроля производством триполифосфата натрия. Триполифосфат натрия ($Na_5P_3O_{10}$) — важное химическое соединение, широко используемое в различных отраслях промышленности, включая пищевую, химическую и фармацевтическую. Используется в качестве стабилизатора, загустителя и умягчителя воды. Создание эффективной системы управления процессом экстракции триполифосфата натрия является актуальной задачей для повышения эффективности производства и обеспечения качества продукции. Для оптимизации этого процесса и повышения его эффективности большое значение имеет создание системы управления процессом экстракции триполифосфата натрия. Актуальность данной проблемы обусловлена тем, что процесс получения триполифосфата натрия имеет определенные трудности и зависит от температуры, давления, соотношения реагентов и др. в зависимости от зависимости. Это связано с необходимостью контроля и корректировки различных параметров. В результате была разработана автоматизированная модель сушильных башен для повышения эффективности и снижения затрат в промышленности триполифосфата натрия.

Ключевые слова: *система автоматического управления, экстракционный процесс, сушильные башни, математическая модель.*

Received: 17 November 2022
Accepted: 16 March 2023
Available online: 31 March 2023