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Technological modeling and management of the re-circulating water system for light industry finishing enterprises

Modelado tecnológico y gestión del sistema de recirculación de agua para empresas de acabado de la industria ligera

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Content

ABSTRACT:
Currently, the most rational solution of the problem of environmental pollution by sewage of light industry finishing enterprises is the introduction of new integrated technologies for separate treatment with the re-circulation use of treated water in technological processes. The effective operation of water treatment facilities is ensured, first of all, by their qualitative design. The design loads on the technological scheme of treatment in general and on each element of treatment facilities should at least be correctly calculated, based on the accepted pollution indicators of original, treated and circulating water. The determination of these loads on each facility is of paramount importance when solving the problem of project rationalization, optimization and technological modeling. The most rational solution would be to obtain a universal method for calculating the loads on treatment facilities, regardless of the variety of technological schemes and the initial indicators of wastewater. This is possible only

RESUMEN:
Actualmente, la solución más racional del problema de la contaminación ambiental por las aguas residuales de las empresas de acabado de la industria ligera es la introducción de nuevas tecnologías integradas para el tratamiento separado con el uso de recirculación del agua tratada en procesos tecnológicos. El buen funcionamiento de las instalaciones de tratamiento de agua se asegura, en primer lugar, por su diseño cualitativo. Las cargas de diseño en el esquema tecnológico de tratamiento en general y en cada elemento de las instalaciones de tratamiento deben ser calculadas correctamente, basándose en los indicadores de contaminación aceptados de agua original, tratada y circulante. La determinación de estas cargas en cada instalación es de suma importancia para resolver el problema de la racionalización de proyectos, optimización y modelización tecnológica. La solución más racional sería obtener un método universal para calcular las cargas en las instalaciones de tratamiento,

on the basis of drawing up the tasks of project optimization, technological modeling and solving the equations of material balances of re-circulating technological systems.
Keywords Separate treatment, project rationalization, equation of material balances, technological modeling, structural loads, environmental safety.

independientemente de la variedad de esquemas tecnológicos y los indicadores iniciales de las aguas residuales. Esto sólo es posible sobre la base de la elaboración de las tareas de optimización de proyectos, modelización tecnológica y resolución de las ecuaciones de balances materiales de sistemas tecnológicos recirculantes.
Palabras clave Tratamiento separado, racionalización de proyectos, ecuación de balances de materiales, modelización tecnológica, cargas estructurales, seguridad ambiental.

1. Introduction

Currently, it is extremely important to develop scientifically based, universal and highly efficient water supply and process wastewater treatment systems in order to create environmentally friendly re-circulating systems in enterprises (Toibayev and Taubaldiyeva, 2016).

The quality, safety and cost of manufactured products largely depend on the quality of water and the organization of the water industry of an industrial enterprise. In addition, it is necessary to creatively generalize all the experience accumulated in this field and create a theoretical basis for a fundamentally new approach to solving the problems posed by life with the help of mathematical and functional models of treatment.

The main source of the environmental hazard of light industry finishing enterprises is the discharge of untreated or insufficiently treated process wastewater into the system of external sewerage and further into surface water bodies. In terms of the volume of water consumed and produced process wastewater, these enterprises are inferior only to such water-intensive industries as chemical, petrochemical, pulp and paper industry, etc.

When developing new water treatment facilities as well as reconstructing and optimizing existing water treatment facilities of finishing enterprises, the following main groups of water-saving measures should be guided (Toibayev and Slyambaeva, 2016; Toibayev et al., 2016):

1) improvement and modernization of machinery and production technology by replacing them with high-tech equipment that reduces water consumption and discharge;

2) development and implementation of integrated treatment technology and re-circulating water systems, new types of apparatus and structures;

3) qualitative design and optimization of technology for separate wastewater treatment of finishing enterprises in terms of quantitative and qualitative composition for individual slightly polluted and heavily polluted streams.

In connection with the foregoing, the present paper has developed the questions of optimizing the technological process of treatment and re-circulating water supply of finishing enterprises by developing mathematical and functional models.

The main technological processes of finishing industries are known to be carried out in an aquatic environment. The complexity of technological and physicochemical processes occurring during the finishing of textile materials and the special role of water in these processes is explained by the complexity of introducing re-circulating water systems in finishing enterprises. As a result of the repeated use of treated water, an increase in the concentration of pollutants and salinity is observed in it. An increase in the concentration of impurities worsens the process of finishing textile materials and leads to a decrease in its technological performance. Therefore, for a long time, technologists believed that the introduction of a re-circulating system in finishing enterprises was impossible, since it inevitably leads to a reduction in the effectiveness of finishing textile materials achieved on fresh water and in its quality.

Targeted research in the field of development and implementation of re-circulating water systems in finishing enterprises that provide the environmental safety and study the extent of impact of the environmental and economic damage caused by them both at the local and regional and at the national level remains poorly understood. Mathematical and functional modeling of the technology of re-circulating water systems (Toibayev, Omarbekuly and Rysbayuly, 2006; Toibayev, 2012), which make it possible to optimize the process by changing the controlled treatment parameters even at the stage of design development and determination of the most rational technological scheme of treatment in each particular case, also remains insufficiently studied.

2. Method

The methodological basis for the development of treatment technology and re-circulating water supply of finishing enterprises is formed by the concept presented by the State Research Center of the Russian Research Institute of VODGEO, which recommends the integrated development of water supply technology for industrial enterprises, including the optimization and ecologization of water use in all operations, workshops and industries.

Therefore, the present paper proposes a comprehensive system approach using mathematical and functional modeling methods, which makes it possible to optimize the treatment process by changing the controlled parameters of treatment facilities and choose the most rational technological scheme of wastewater treatment in each specific case at the stage of design development.

3. Discussion and Results

Mathematical model of wastewater treatment technology of finishing enterprises

The most rational solution would be to obtain a universal method for calculating the loads on treatment facilities, regardless of the variety of technological schemes and the initial indicators of wastewater. This is possible only on the basis of generating and solving the equation of material balances of re-circulating technological systems. Therefore, the definition of these loads is also of paramount importance in the solution of the problem of project optimization.

The process of wastewater treatment is characterized by a system of indicators of the quality of treated water. After exiting the technological cycle, polluted water contains various components. The main components are suspended solids, dry residue, synthetic surfactants, dyes and chemical oxygen demand (COD). The quantitative and qualitative composition of these components determines the physico-chemical state of wastewater: whether this water flow is weakly or strongly polluted. Proceeding from this, a state vector of wastewater is compiled.

A state vector is a variable depending on the treatment method, the cycle of the turnover of treated wastewater, etc. Each component of the state vector is measured in mg/dm^3.

$$V = \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \end{bmatrix} = \begin{bmatrix} \text{suspended solids, mg/l} \\ \text{dry residue, mg/l} \\ \text{synthetic surfactants, mg/l} \\ \text{dyes, mg/l} \\ \text{COD, mg/l} \end{bmatrix} \quad (1)$$

According to the regulatory requirements for the quality of re-circulating water for the main technological processes, developed by Toibayev and Omarbekuly (2004) and Toibayev, Omarbekuly and Rysbayuly (2006), the following vectors are compiled:

$$V_{w,d.}^{perm} = \begin{bmatrix} 0-30 \\ 0-4200 \\ 0-20 \\ 0-2 \\ 0-150 \end{bmatrix}, \quad V_{d.}^{perm} = \begin{bmatrix} 0-8 \\ 0-1500 \\ 0-2 \\ 0 \\ 0-30 \end{bmatrix}, \quad V_{w,bl,}^{perm} = \begin{bmatrix} 0-30 \\ 0-4200 \\ 0-50 \\ 0-2 \\ 0-150 \end{bmatrix} \quad (2)$$

where: $V_{w,d.}^{perm}$ is the permissible concentration of pollution in circulating water for the washing process after dyeing;

$V_{d.}^{perm}$ is the permissible concentration of pollution in circulating water for the preparation of dyeing solutions and dyeing;

$V_{w,bl,}^{perm}$ is the permissible concentration of pollution in circulating water for the washing process after bleaching and boiling.

Note that all the components of the vector $V_{w,d.}^{perm}$, $V_{d.}^{perm}$ and $V_{w,bl,}^{perm}$ are intervals and measured in mg/dm^3.

Further, in our discussion, a special place is occupied by the main methods (facilities) of wastewater treatment. Therefore, we introduce the following designations of facilities: TT_1- pressure floatation unit, TT_2 – thin-layer settler, TT_3 – granular filter, TT_4 – ion-exchange filter and TT_5 – ozonator.

For the main technological processes of finishing textile materials, the following designations are introduced: TP_1 - washing of textile materials after dyeing; TP_2 - preparation of dyeing solutions and dyeing; TP_3 - washing of textile materials after bleaching and boiling.

The following indices are introduced in order to get quickly oriented in the indicated designations in the turnover process of treated water:

i is the number of the vector component of wastewater status, for example: V_1 - suspended solids, V_4 - dyes, etc.;

J is the number of the treatment (facility) method, for example: J=3 means that wastewater has passed through a particulate filter, etc.;

k is the number of the technological process of finishing textile materials, for example: k=1 – wastewater is used for washing after dyeing;

n is the number of the turnover cycle of treated water.

The state vector of circulating water depends on the technological process, on the treatment method. In addition, it varies depending on the cycle of water rotation. Therefore, in the n-th turnover of treated wastewater after the J-th washing, the state vector is denoted as:

$$V_J^{n,k} = V^n\left(TP_k, TT_J\right) \tag{3}$$

According to the separate treatment method proposed by the authors Toibayev K.D. and Taubaldiyeva A.S. (2016) and Toibayev K.D., Taubaldiyeva A.S. and Kassabekova G.T. (2015), wastewater of the finishing enterprise is divided into two main streams: slightly polluted and heavily polluted.

The state vector of a slightly polluted wastewater stream is denoted as $\widetilde{V}_J^{n.,k}$, and a strongly polluted wastewater stream – as $\overline{V}_J^{n,k}$.

In order for a heavily polluted wastewater stream to be discharged into the city sewage system or into water channels, the state vector of wastewater pollutants must satisfy a certain condition. In our case, the pollution status vector must be contained in the state vector of the maximum permissible content (MPC) in the city sewage system or in water channels. Therefore, the state MPC vector is introduced:

$$V_{MPC}^{sewage} = \begin{bmatrix} 0-500 \\ 0-1000 \\ 0-20 \\ 0-15 \\ 0-900 \end{bmatrix} \quad V_{MPC}^{wat.channel} = \begin{bmatrix} 0-31,21 \\ 0-437,5 \\ 0-0,21 \\ 0-0,05 \\ 0-25 \end{bmatrix} \qquad (4)$$

Definition. If all the vector components $V_J^{n,k}$ are contained in the corresponding vector components V_{MPC}^{sewage}, then they say that the vector $V_J^{n,k}$ is contained in V_{MPC}^{sewage} or that $V_J^{n,k}$ entered the state V_{MPC}^{sewage} and is denoted by the symbol:

$$V_J^{n,k} \subset V_{MPC}^{sewage} \qquad (5)$$

In terms of the coordinate form this inclusion is written in the following form:

$$V^{n,k}[i] \in V_{MPC}^{perm}[i],\ i=1, 2, 3, 4, 5 \qquad (6)$$

If the state vector $V_J^{n,k}$ does not satisfy the requirements of the MPC, then it is briefly written as follows:

$$V_J^{n,k} \not\subset V_{MPC}^{sewage} \qquad (7)$$

After the next treatment cycle, the state vector takes on new values, i.e. the vector components V get new values. The relationship between the old and new values is carried out through the treatment coefficient. Each component of the vector $V_J^{n,k}$ gets new values in different ways, i.e. the treatment coefficients of each component differ from each other. In connection with this, the concept of "the treatment coefficient vector $\alpha(TO_J)$" is introduced.

Using these designations, we compile a technological model of the wastewater treatment scheme, as seen in Figure 1a, b.

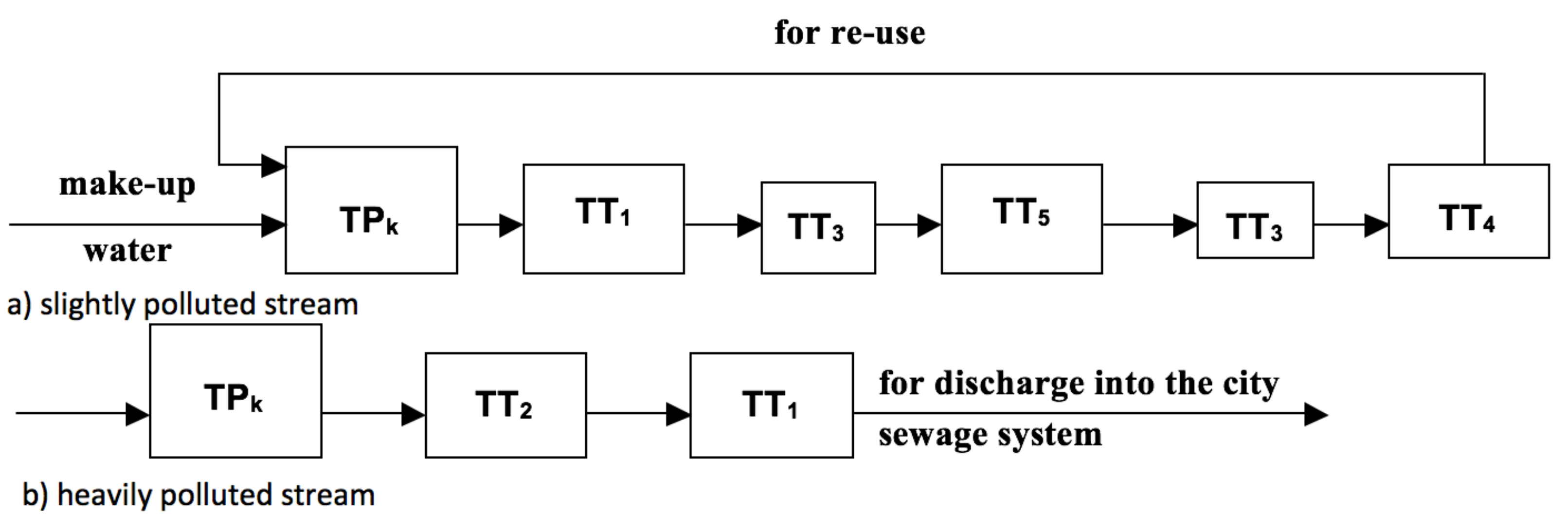

Figure 1 (a, b). Technological model of the treatment scheme of slightly polluted and heavily polluted streams

If $\alpha(TT_J)$ is denoted by α_J, then for a heavily polluted wastewater stream the treatment coefficient vector in the thin-layer settler and the pressure flotation unit will look as follows:

$$\alpha_2 = \begin{bmatrix} 0,43 \\ 1 \\ 0,86 \\ 0,65 \\ 0,81 \end{bmatrix}, \quad \alpha_1 = \begin{bmatrix} 0,48 \\ 1 \\ 0,63 \\ 0,66 \\ 0,36 \end{bmatrix}$$

For a slightly polluted wastewater stream the treatment coefficient vector in facilities (pressure flotation unit, granular filter, ozonator and ion exchange filter) will be recorded as follows.

$$\alpha_1 = \begin{bmatrix} 0,35 \\ 1 \\ 0,37 \\ 0,46 \\ 0,79 \end{bmatrix} \quad \alpha_3 = \begin{bmatrix} 0,11 \\ 1 \\ 1 \\ 0,82 \\ 0,91 \end{bmatrix} \quad \alpha_5 = \begin{bmatrix} 1 \\ 1 \\ 0,15 \\ 0,1 \\ 0,2 \end{bmatrix} \quad \alpha_3 = \begin{bmatrix} 0,11 \\ 1 \\ 1 \\ 0,82 \\ 0,91 \end{bmatrix} \quad \alpha_4 = \begin{bmatrix} 0,03 \\ 0,33 \\ 0,1 \\ 0,05 \\ 0,15 \end{bmatrix} \qquad (8)$$

Note: The i-th component of the state vector, the treatment coefficient or permissible concentration is denoted by $\widetilde{V}_J^{n.,k}$ [i], α_J[i], $V_{d.}^{perm}$ [i], V_{MPC}^{sewage} [i].

After the next treatment cycle, the state vector receives a new value, which is obtained from the old one by multiplying the components by the corresponding components of the treatment coefficient vector.

The standard definition of the scalar product of two vectors is given by Bronstein I.N. and Semendyaev K.A. (1981) and Lancaster P. (1982). In our case, the above products of two vectors are unacceptable. In this regard, based on the technological cycle of finishing textile materials and setting research objectives, we propose another product of two vectors. In this case, the product of two vectors will again be a vector (Toibayev et al., 2016; Zhizhilev, 2002).

Definition. The vector of the component, which is obtained by the product of the corresponding components of two vectors, is called the direct product of these vectors, i.e.:

$$A=\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix}, \quad B=\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix}, \quad C=\begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{bmatrix}$$

If $c_i=a_i \cdot b_i$, i=1,2...5, then the vector C is the direct product of the vectors A and B, and is denoted by:

$$C = A \cdot B \tag{9}$$

Consider the technological treatment scheme of the heavily polluted stream (see Figure 1b).

Let the pollution indicator of process water is V_{water}, and after the technological process pollution V^{k}_{proc} will be added. In this case, after treatment carried out according to the scheme presented in Figure 1b, the state vector is obtained:

$$V=(V_{water}+V^{k}_{proc})\cdot\alpha_1\cdot\alpha_2$$

As soon as the inclusion is performed $(V_{water}+V^{k}_{proc})\cdot\alpha_1\cdot\alpha_2 \subset V^{sewage}_{MPC}$ or $(V_{water}+V^{k}_{proc})\cdot\alpha_1\cdot\alpha_2 \subset V^{wat.channel}_{MPC}$, treated water can be discharged into the city sewage system or water channel.

Now consider the technological treatment scheme of a slightly polluted stream (see Figure 1a).

After the first cycle of full turnover, we obtain:

$$V^1= (V_{water}+V^{k}_{proc})\cdot\alpha_1\cdot\alpha_3\cdot\alpha_5\cdot\alpha_3\cdot\alpha_4 \tag{10}$$

Denote it by $\alpha=\alpha_1\cdot\alpha_3\cdot\alpha_5\cdot\alpha_3\cdot\alpha_4$ (11)

where: α is the vector of the treatment coefficient according to the technological scheme shown in Figure 1a. The components of the vector α are calculated using the direct product of vectors from the vectors (8).

Taking into account (11), the equation (10) has the following form:

$$V^1= (V_{water}+V^{k}_{proc})\cdot\alpha \tag{12}$$

The upper index of the vector V^1 indicates the number of the water cycle.

After the second water cycle, the state vector of circulating water is calculated by the formula:

$$V^2 = (V^1 + V^{k}_{proc} + V_{make\text{-}up}) \cdot \alpha \tag{13}$$

where $V_{make\text{-}up}$ is the pollution indicator of make-up water.

Taking into account (12) from (13), we obtain the equation:

$$V^2 = (V_{water} + V^{k}_{proc}) \cdot \alpha^2 + V_{tp} \cdot \alpha \tag{14}$$

where $V_{tp} = V_{make\text{-}up} + V^{k}_{proc}$ (15)

After the third water cycle of treated wastewater, we obtain

$V^3 = (V^2 + V^{k}_{mex} + V_{make\text{-}up}).\alpha$ or with regard to (15)

$$V^3 = (V_{water} + V^{k}_{proc}) \cdot \alpha^3 + V_{tp} \cdot \alpha^2 + V_{tp} \cdot \alpha \tag{16}$$

Repeating this process many times, after the n-th cycle, we obtain the formula:

$$V^n = (V_{water} + V^{k}_{proc}) \cdot \alpha^n + V_{tp} \cdot \alpha(\alpha^{n-2} + \ldots + \alpha + E) \tag{17}$$

where: $E = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$ is the unit vector.

On the basis of the direct product of vectors introduced by us, the following formula is valid:

$$E + \alpha + \alpha^2 + \ldots + \alpha^{n-2} = \frac{E - \alpha^{n-1}}{E - \alpha} \tag{18}$$

Therefore, taking into account (18), we obtain the following equation:

$$V^n = (V_{water} + V^{k}_{proc}) \cdot \alpha^n + V_{tp} \frac{E - \alpha^{n-1}}{E - \alpha} \cdot \alpha \tag{19}$$

Based on (8) and (9), we obtain $\alpha^n \to \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$ at $n \to \infty$

Therefore, after the re-use of treated water in the turnover system, we get:

$$V^n = V_{tp} \frac{\alpha}{E-\alpha} \text{ or } V^n = (V_{make\text{-}up} + V^k_{proc}) \frac{\alpha}{E-\alpha} \qquad (20)$$

It is clear from (19) that after the re-use of recirculating water, the influence of the initial state vector $V_{water} + V^k_{mex}$ on the state vector disappears.

The first part of the formula (20) does not depend on the water cycle, and therefore, omitting the index n from (20), we obtain:

$$V = (V_{make\text{-}up} + V^k_{proc}) \frac{\alpha}{E-\alpha} \qquad (21)$$

The obtained formula shows that the technological process is established.
Using the formula (21), we can draw the following important conclusions.

$$\text{If } (V_{make\text{-}up} + V^k_{proc}) \frac{\alpha}{E-\alpha} \subset V^k_{perm}, \qquad (22)$$

where: $V^1_{perm} = V^{perm}_{w,d.}$, $V^2_{perm} = V^{perm}_{d.}$, $V^3_{perm} = V^{perm}_{w,bl,}$ are the given state vectors from (2), then water used in the technological process can be put into circulation, the pollution indicators of circulating water are established and do not go beyond the permissible norm. In this case, water after the first cycle of the technological scheme by number k is classified as slightly polluted.

If the inclusion (22) for the processing line by number k is not performed, wastewater is classified as heavily polluted. Therefore, after preliminary treatment, such water can be discharged into the sewage system immediately or after several (two, three) circulations. In this case, the process of circulating water pollution is established, but the inclusion (22) will be violated.

Note: if $\alpha = \begin{bmatrix} \alpha[1] \\ \alpha[2] \\ \alpha[3] \\ \alpha[4] \\ \alpha[5] \end{bmatrix}$, then $E - \alpha = \begin{bmatrix} 1-\alpha[1] \\ 1-\alpha[2] \\ 1-\alpha[3] \\ 1-\alpha[4] \\ 1-\alpha[5] \end{bmatrix}$

Therefore, the formula (22) in a coordinate form is as follows:

$$V_i = (V^k_{proc}[i] + V_{make\text{-}up}[i]) \cdot \frac{\alpha[i]}{1-\alpha[i]};\ \text{где } i=1,2,3,4,5$$

Then the inclusion (22) can be written in the form: $V[i] \in V^k_{perm}[i]$, i=1,2...5

Note. In the process of wastewater treatment, a number of factors influence the value of the coefficients (8). By changing some controlled parameters of individual water treatment facilities, one can reduce the value of the treatment coefficient vector (8), i.e. increase the efficiency of individual treatment facilities and the technological treatment scheme in general. Therefore, the next section will consider the functional scheme of wastewater treatment in accordance with Figure 1.

Functional model of wastewater treatment technology of finishing enterprises

The main key elements of the functional model of the technological treatment scheme, according to Figure 1a, b, are treatment methods (TT_J). Therefore, TT_J is located inside the rectangle (see Figure 2). Figure 2 shows that the state vector $V_{J_1}^{n,k}$ under J_1, passing through TT_J receives a new state $V_J^{n,k}$. The state $V_{J_1}^{n,k}$ is affected, firstly, by the TT_J technological process itself and its controlled parameters. In Figure 2, the controlled parameters affect the rectangle from below, and the basic treatment parameters J – from above.

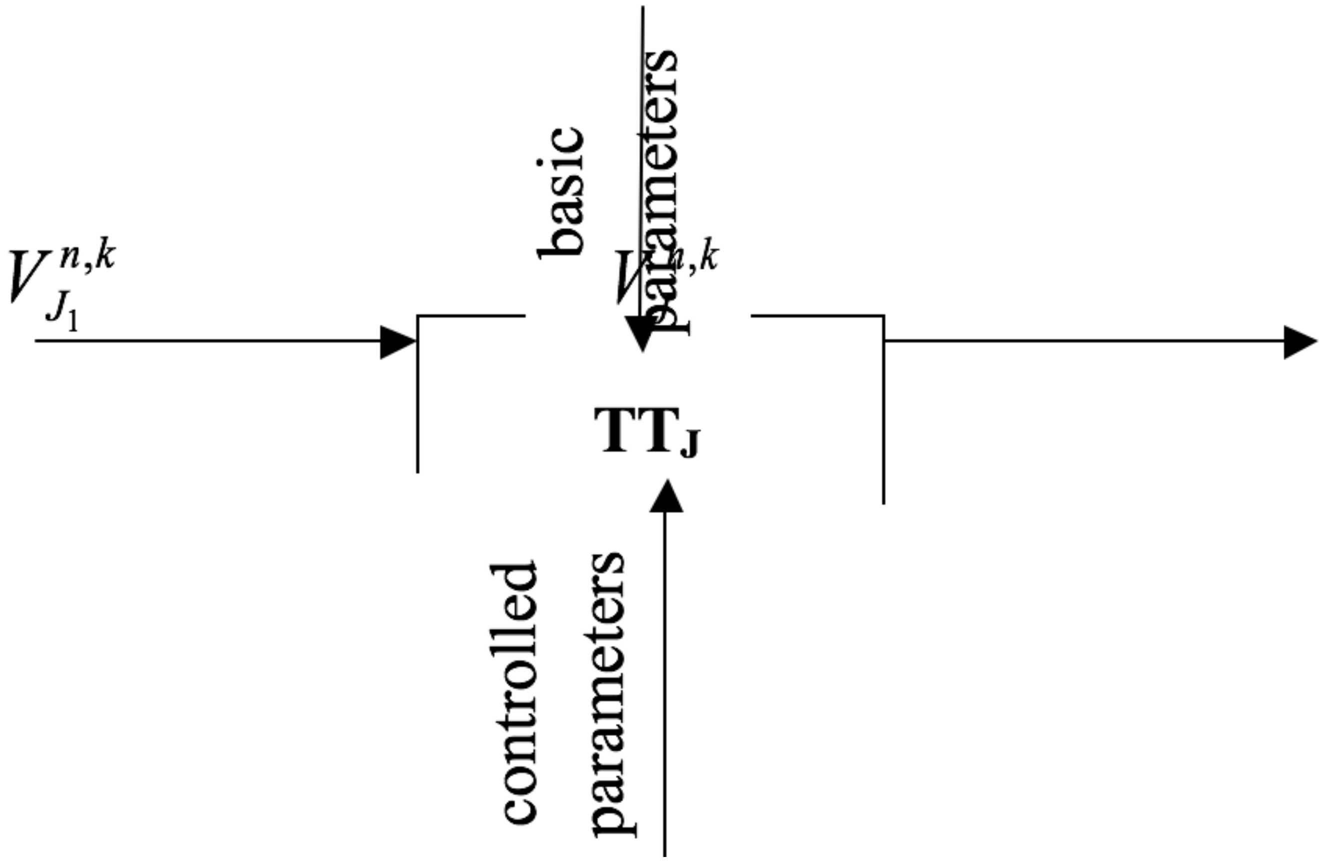

Figure 2. Functional model of wastewater treatment technology

Using Figure 2, we compose the elements of a functional model of the technological treatment scheme of slightly and heavily polluted wastewater (see Figure 1a, b). Figures 3-7 show the functional diagrams of individual facilities of the technological treatment scheme.

Consider the thin-layer settler. Figure 3 shows that by changing the distance between the shelves of the basin, the rate of wastewater supply and the dose of the coagulant, it is possible to improve the indicators $V_2^{n,k}$.

The smaller the components of this vector, the more efficiently the thin-layer settler. In order for the sedimentation basin to operate, there is a need for water supply, coagulant, etc. These parameters in Figure 3 affect TT_2 from above.

Figure 4 shows the functional scheme of wastewater treatment by the method of pressure flotation. Wastewater with the indicators $V_{J_1}^{n,k}$, entering the pressure flotation unit, comes out of it having new indicators $V_1^{n,k}$.

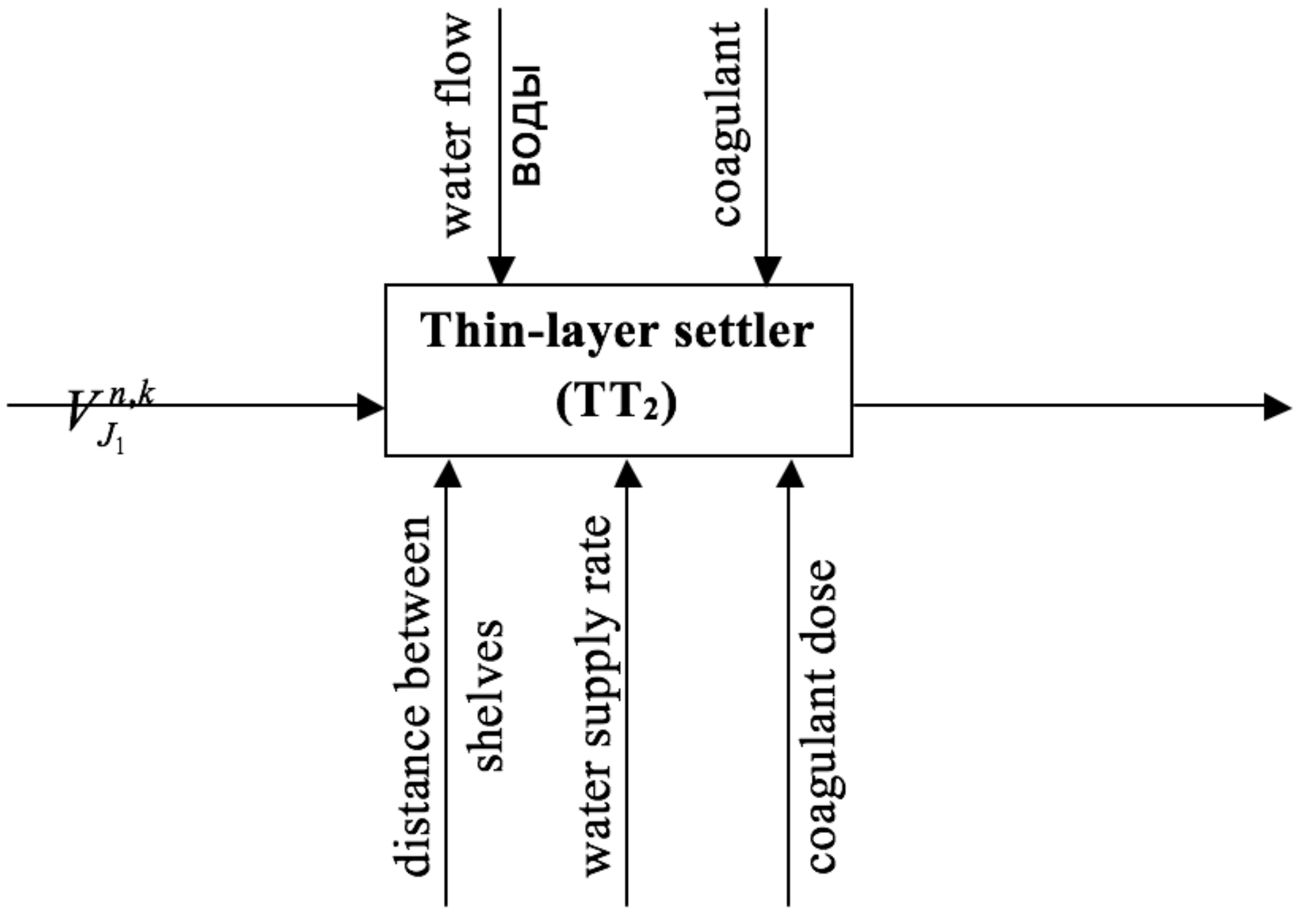

Figure 3. Functional scheme of the thin-layer settler

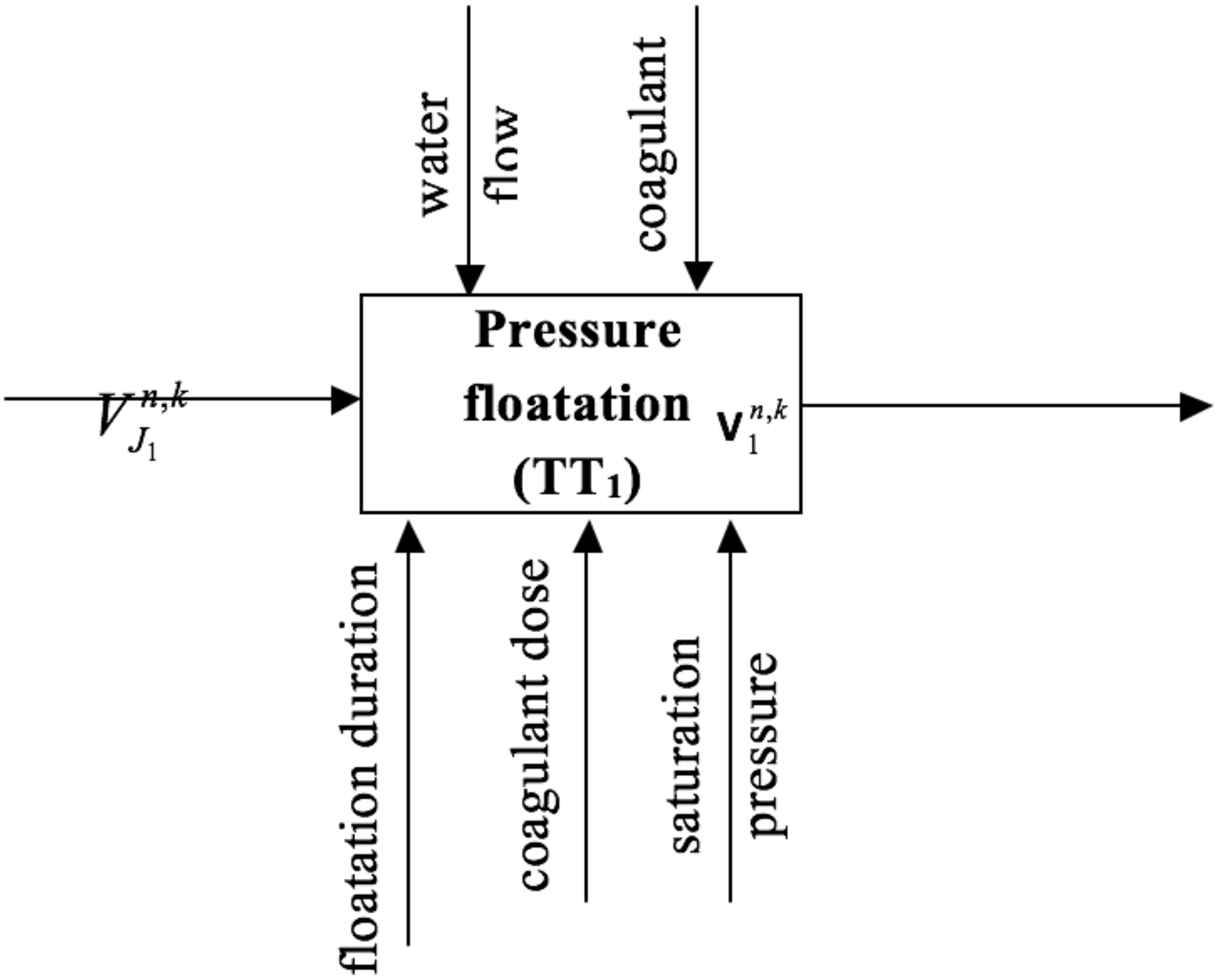

Figure 4. Functional scheme of the pressure floatation unit

Due to the efficiency coefficients of pressure flotation α_1, all the components of the vector $V_{J_1}^{n,k}$ decrease by a certain amount, since $V_1^{n,k} = V_{J_1}^{n,k} \cdot \alpha$.

By varying the duration of flotation, the dose of the coagulant and the saturation pressure, it is possible to reduce the components of the efficiency vector α_1. In this case, the equality $V_5^{n,k} = V_{J_1}^{n,k} \cdot \alpha$ is valid.

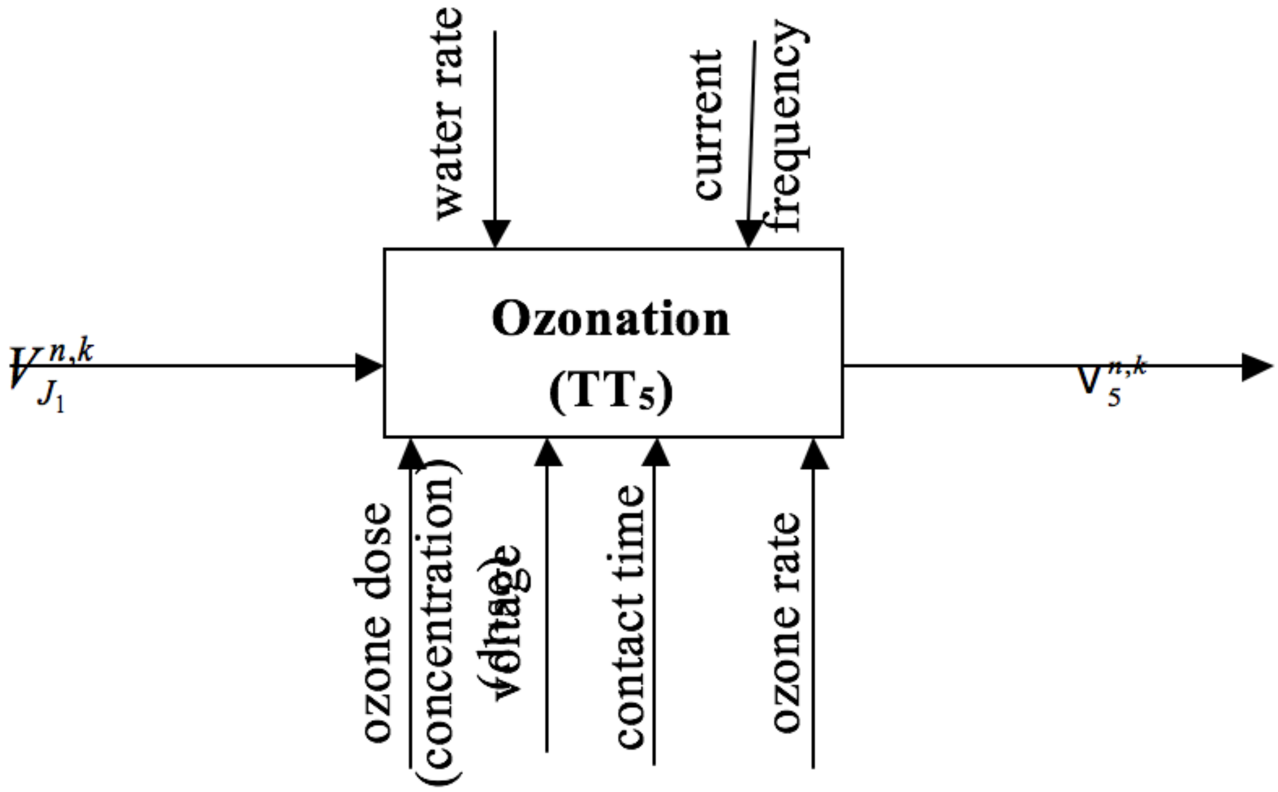

Figure 5. Functional scheme of the ozonator

The optimum ozone dose is determined by the ozone flow rate, the water supply rate to the column, and the contact time (reaction rate). Therefore, these parameters in the ozonation of water are attributed to the controlled parameters of the ozonator.

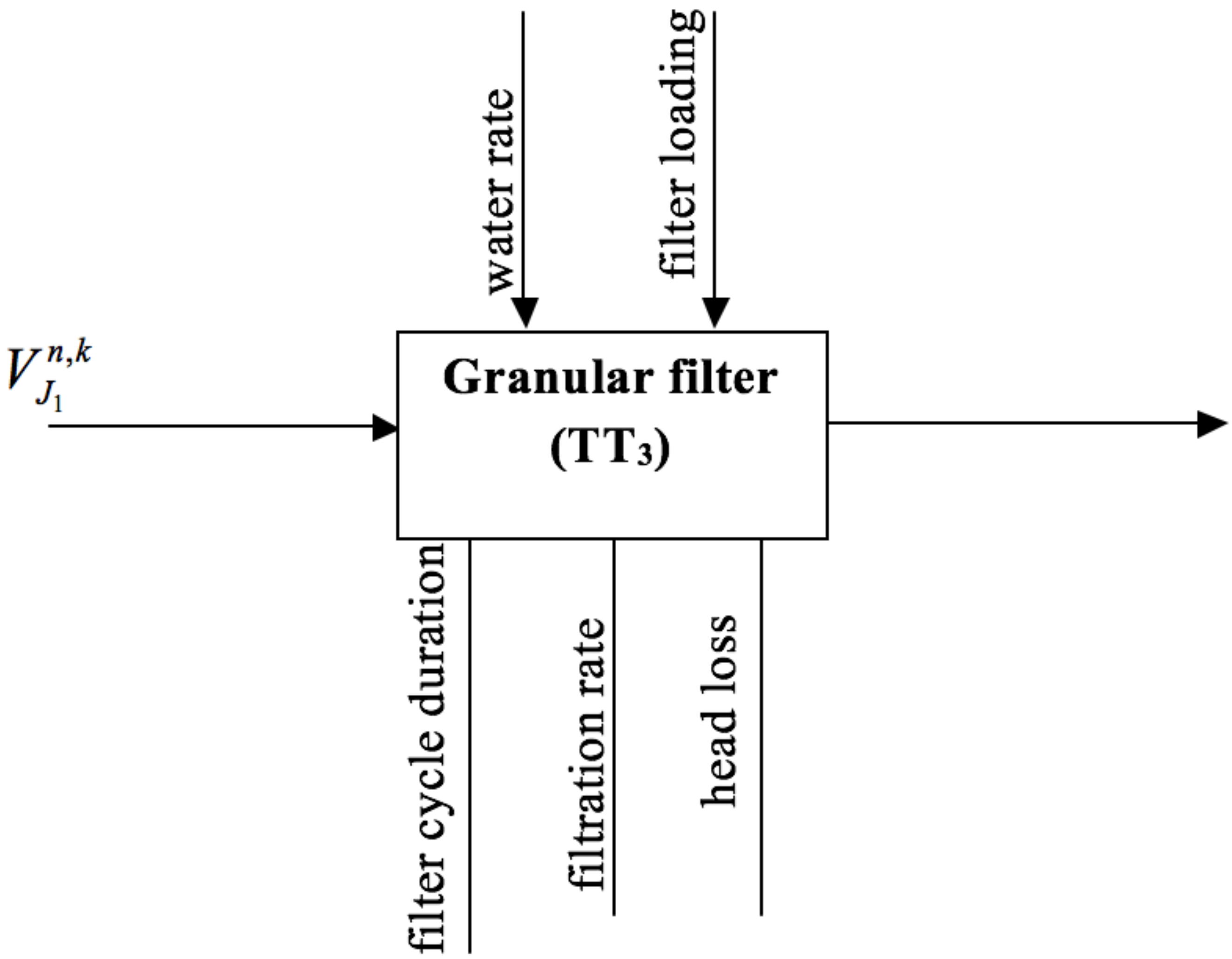

Figure 6. Functional scheme of the granular filter

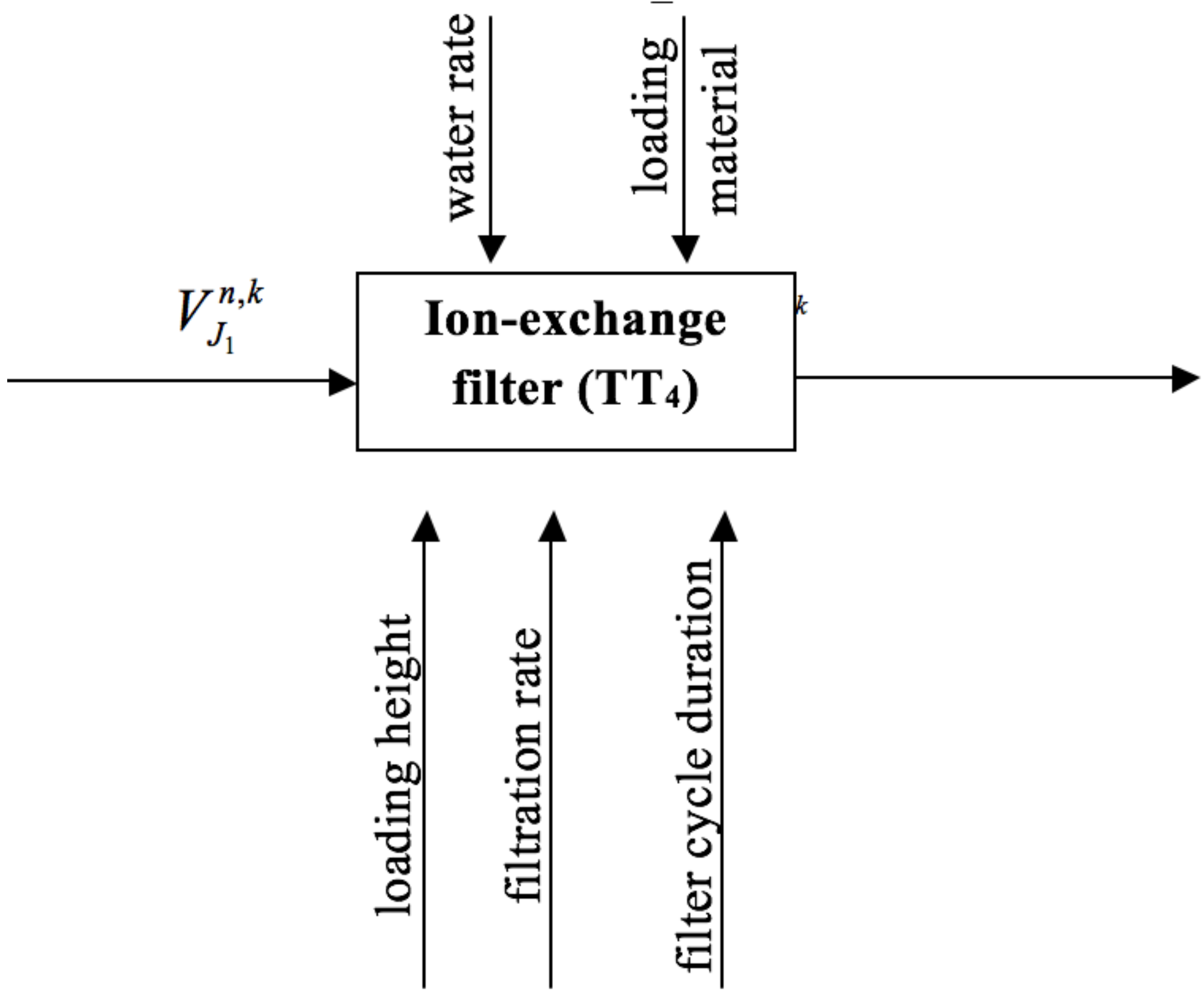

Figure 7. Functional scheme of the ion-exchange filter

The functional technological treatment scheme of a heavily polluted stream (see Figure 8) is based on the functional schemes of individual facilities (Figures 3-4) and on the basis of the structural scheme of wastewater treatment (Figure 1b). As can be seen from Figure 8, by controlling the parameters (the distance between the shelves, the water supply rate, the dose of the coagulant of the thin-layer settler (TT2), and the duration of flotation, the coagulant dose and the saturation pressure of the pressure flotation tank TT1), we achieve the inclusion of $V_1^k \subset V_{MPC}$. After that, treated water is discharged into the city sewage system.

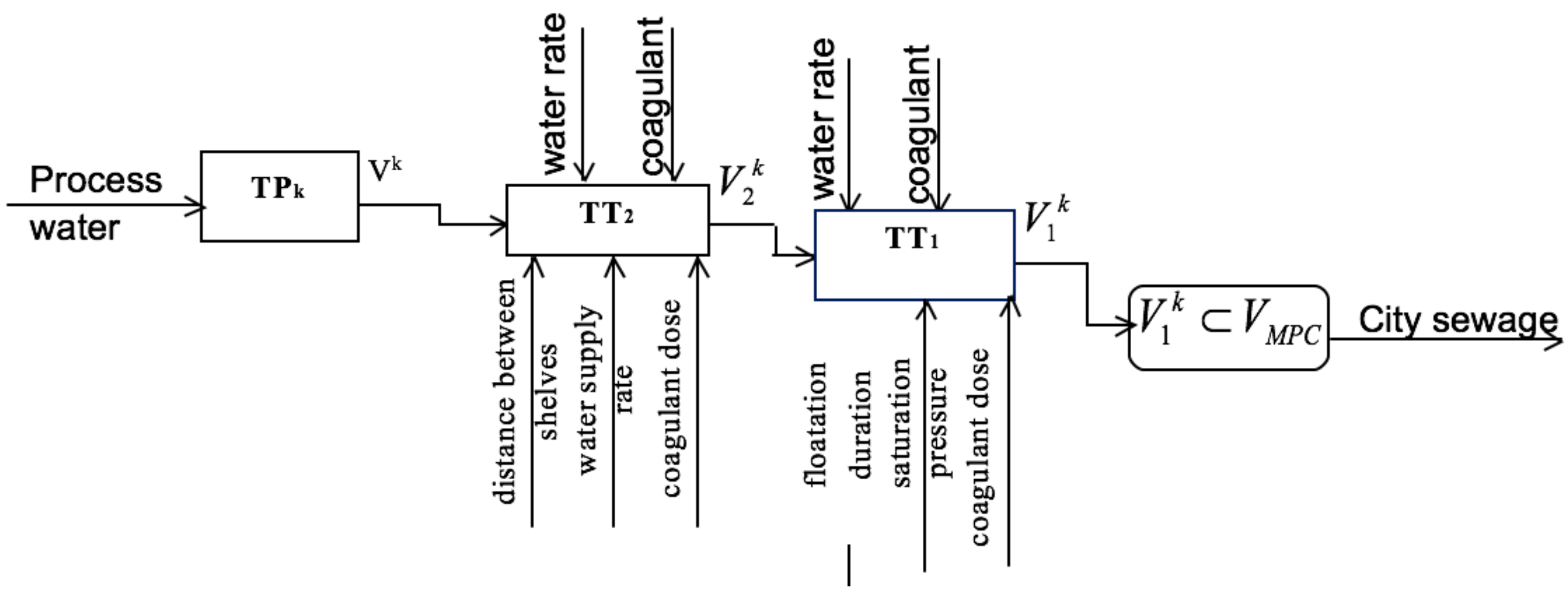

Figure 8. Functional treatment scheme of a heavily polluted stream

The functional treatment scheme of a slightly polluted stream is shown in Figure 9. It can be seen from Figure 9 that after TP_k polluted wastewater having the indicators $V_{proc}^{n,k}$ goes to the pressure floatation unit (TT_1), then having the indicator $V_1^{n,k}$ it enters the granular filter (TT_3), and treated wastewater will have the characteristic $V_3^{n,k}$.

During flotation, the controlled parameters include flotation duration, saturation pressure and coagulant dose, and during filtering – filtration rate, filter cycle duration and head loss. It means that by controlling the above parameters of the flotation unit, one can improve the parameters $V_1^{n,k}$, and by controlling the parameters of the granular filter, one can improve the parameters $V_3^{n,k}$. Further, wastewater enters the ozonator and exits it with the indicator $V_5^{n,k}$, which can be improved by changing ozone concentration, voltage and contact time. Wastewater passes through the granular filter repeatedly to remove residual concentrations of suspended solids.

Then treated water is directed to the ion-exchange filter, after which it should have an indicator, which is determined by the formula:

$$V_4^{n,k} = V^{n,k} = V_{proc}^{n,k} \cdot \alpha_1 \cdot \alpha_3 \cdot \alpha_5 \cdot \alpha_3 \cdot \alpha_4 = V_{proc}^{n,k} \cdot \alpha \quad (23)$$

Changing the controlled parameters TT_1, TT_3, TT_4 and TT_5, we are trying to include $V^{n,k} \subset V^{perm}$.

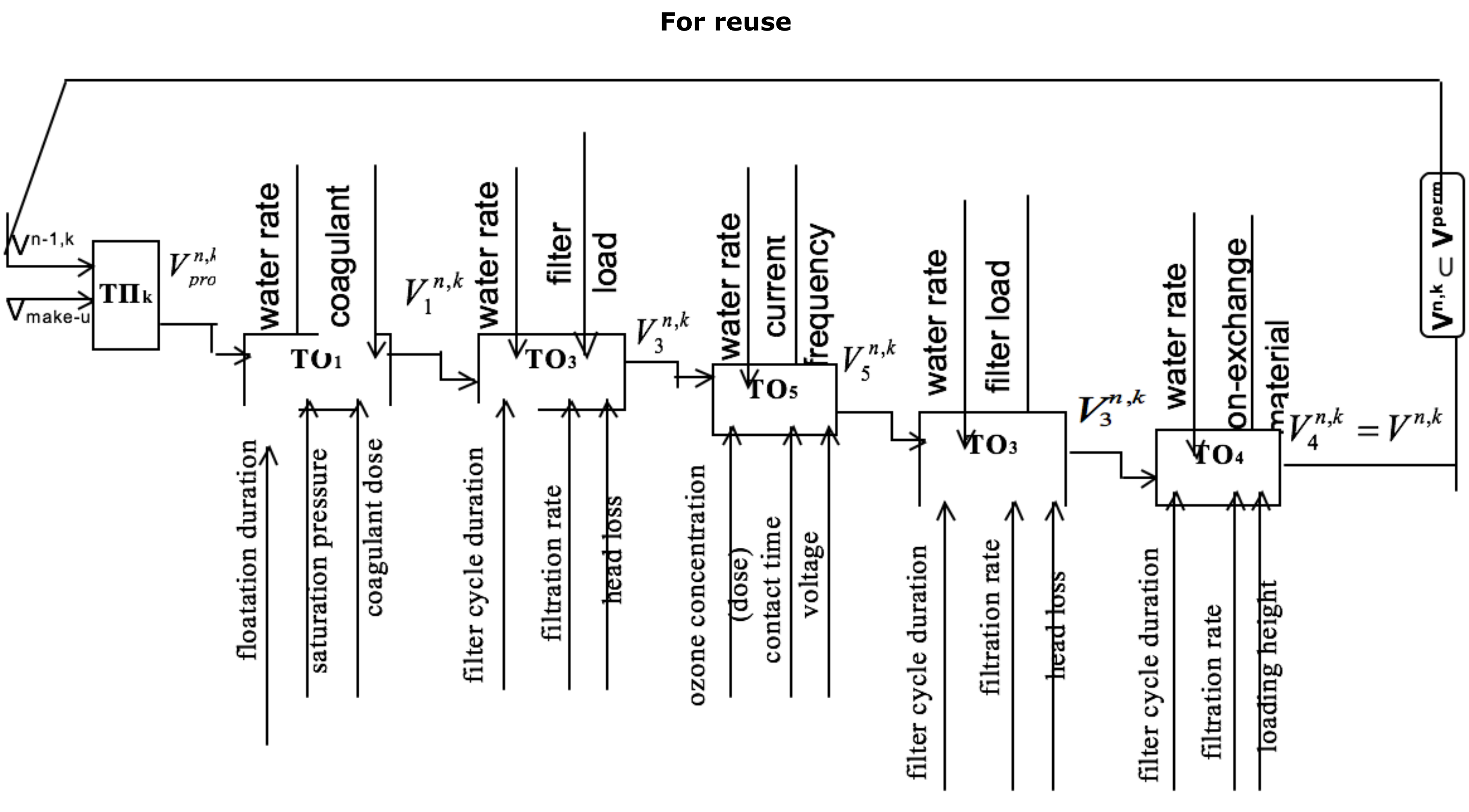

Figure 8. Functional treatment scheme of a slighly polluted stream

Analyzing the experiments carried out in this study, it is possible to form the vectors of the treatment coefficient for a heavily polluted stream:

$$\alpha_2=\begin{bmatrix}0,43\\1\\0,86\\0,65\\0,81\end{bmatrix},\ \alpha_1=\begin{bmatrix}0,48\\1\\0,63\\0,66\\0,36\end{bmatrix}$$

For a slightly polluted wastewater stream, the treatment coefficient vectors are seen as follows:

$$\alpha_1=\begin{bmatrix}0,35\\1\\0,37\\0,46\\0,79\end{bmatrix}\quad \alpha_3=\begin{bmatrix}0,11\\1\\1\\0,82\\0,91\end{bmatrix}\quad \alpha_5=\begin{bmatrix}1\\1\\0,15\\0,1\\0,2\end{bmatrix}\quad \alpha_3=\begin{bmatrix}0,11\\1\\1\\0,82\\0,91\end{bmatrix}\quad \alpha_4=\begin{bmatrix}0,7\\0,8\\0,7\\0,7\\0,75\end{bmatrix}$$

The treatment coefficient vector of a heavily polluted wastewater stream was determined according to the following indicators and amounted to:

1) suspended solids: $\alpha_2[1]\cdot\alpha_1[1]=0,43\cdot0,48=0,21$

2) dry residue: $\alpha_2[2]\cdot\alpha_1[2]=1\cdot1=1$

3) synthetic surfactants: $\alpha_2[3]\cdot\alpha_1[3]=0,86\cdot0,61=0,52$

4) dyes: $\alpha_2[4]\cdot\alpha_1[4]=0,65\cdot0,66=0,43$

5) COD: $\alpha_2[5]\cdot\alpha_1[5]=0,81\cdot0,36=0,3$

The treatment coefficient vector of a slightly polluted wastewater stream was determined according to the following indicators and amounted to:

1) suspended solids: $\alpha_1[1]\cdot\alpha_3[1]\cdot\alpha_5[1]\ \alpha_3[1]\cdot\alpha_4[1]= 0,35\cdot0,11\cdot1\cdot0,11\cdot0,7=0,003$

2) dry residue: $\alpha_1[2]\cdot\alpha_3[2]\ \alpha_5[2]\ \alpha_3[2]\ \alpha_4[2]= 1\cdot1\cdot1\cdot1\cdot0,8=0,8$

3) synthetic surfactants: $\alpha_1[3]\cdot\alpha_3[3]\ \alpha_5[3]\ \alpha_3[3]\cdot\alpha_4[3]= 0,37\cdot1\cdot0,15\cdot1\cdot0,7=0,04$

4) dyes: $\alpha_1[4]\cdot\alpha_3[4]\ \alpha_5[4]\ \alpha_3[4]\ \alpha_4[4]= 0,46\cdot0,82\cdot0,1\cdot0,82\cdot0,7=0,022$

5) COD: $\alpha_1[5]\cdot\alpha_3[5]\ \alpha_5[5]\cdot\alpha_3[5]\ \alpha_4[5]= 0,79\cdot0,91\cdot0,2\cdot0,91\cdot0,75=0,1$

Therefore, a treated, slightly polluted stream using the main parameters of the treatment coefficient vector and certain values of the optimum control parameters of treatment facilities obtained as a result of the experimental studies can be directed to reuse in the technological process of finishing textile materials and products. For this, it is necessary to additionally conduct technological tests to check the suitability of treated water for the washing and dyeing of textile materials.

4. Conclusion

The effective operation of water treatment facilities is ensured, first of all, by their qualitative design. The design loads on the technological scheme of treatment in general and on each element of treatment facilities should at least be correctly calculated, based on the accepted pollution indicators of original, treated and circulating water. The determination of these loads on each facility is of paramount importance when solving the problem of project rationalization, optimization and technological modeling.

By changing the controlled parameters and the values of the treatment coefficient vector of a heavily polluted stream in the functional technological scheme, it is possible to achieve the inclusion of V□□VMPC where treated water is sent for discharge into the city sewage system for further joint treatment with municipal wastewater.

In order to include Vn,k □ Vperm in a slightly polluted stream, treated water is sent to the re-circulating water supply system of the finishing enterprise.

By changing the controlled treatment parameters in the functional technological scheme, it is possible to create an environmentally friendly system of re-circulating water supply for finishing enterprises of light industry and to solve the problems of environmental pollution by sewage in the regions where they are located.

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