Modeling of the process of treatment of polluted washing water in circulating water systems

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Abstract. Optimization of the process of treatment of circulating water is an important scientific and technical task. Consideration of this issue is proposed on the example of cleaning washing water. The creation of water use systems at industrial enterprises in the recycling cycle is associated with the need for a new approach to the formulation of research, design and operation of water recycling systems. The modeling of the process of cleaning polluted washing water in circulating water use systems and solutions to the problems of optimizing the process parameters. We have elaborated a mathematical model of management of circulating water system. Thus, application of the offered technique allows to solve a problem of optimization of process of purification of the polluted waters for circulating systems of water consumption. On the basis of this technique the technological scheme of cleaning of the polluted washing waters is developed is based on application of a combination of ways of destruction of structure of pollution and ways of separation of the destabilized pollution. The technological scheme of cleaning contaminated washing water is based on a modular method of constructing a cleaning device, which is based not on individual ingredients or their dispersion, but on the type of contaminants present: pop-up, sedimentary, suspended-emulsified contaminants.

Introduction

The technological scheme of cleaning contaminated washing water is based on the use of a combination of methods of destruction of the structure of pollution and methods of separation of destabilized pollution. The choice of methods depends on the task and technical and economic factors. Among the technical factors include the possibility of constructive design of the cleaning process, its management and ease of maintenance of equipment. The economic feasibility of the solution is due to the need to solve the problem taking into account the existing costs of equipment, maintenance and payments for water, wastewater discharge and disposal of sludge and oil products.

Conditions for discharge of washing water into the sewer are different. The discharge of water to the city collector the composition of the effluents normalized. The implementation of which predetermines the creation of a drain-free water supply system of the washing complex, regardless of other factors affecting the choice of the cleaning scheme. Washing the complexes of the industrial enterprises there are internal regulations of companies and in the discharge effluent from the system, even if it is negotiable, accounted for the possibility of dilution, averaging and cleaning ability of factory wastewater treatment facilities for individual ingredients and as a whole. Nevertheless, the
main characteristic of the system of water recycling should be considered the volume of water in the system and then the second, hour and daily circulation flow. Since there are two main uses of water: the supply of water to the surface to be cleaned and, conversely, the supply of the object by immersion in water, the listed characteristics will differ, although the dynamics of accumulation of pollution in both cases is the same.

The technological scheme of cleaning contaminated washing water is based on a modular method of constructing a cleaning device, which is based not on individual ingredients or their dispersion, but on the type of contaminants present: pop-up, sedimentary, suspended-emulsified contaminants [1]. For fig. 1 shows the principal three-flow flow diagram of cleaning contaminated washing water. Installations for cleaning contaminated washing water are made in a modular design, which allows them to equip both new and existing technological complexes, as well as to improve them in operation.

![Image](image_url)

**Figure 1.** Principle technological scheme of purification of polluted washing water: 1 – tank-sump contaminated washing water; 2-technological washing plant; 3-sludge collection unit; 4-sedimentation tank; 5-oil collection and purification unit; 6 - unit for cleaning contaminated washing water from emulsified and suspended particles

**Mathematical formulation of the problem**

Formulation of the problem of optimal management of the water use recycling system. The system of treatment of circulating water is set (Fig. 2).

![Image](image_url)

**Figure 2.** Scheme of the reverse water use system: 1-capacity, 2-pumping device, 3-cleaning device
We consider a given period of time $T$, during which the system receives a certain amount of contamination ingredient mass $m_{in}(t)$, $t \in [0, T]$. The cleaning device removes part of the $m_{out}(t)$ contamination from the systems. The rest of the mass $m_{in}(t)$ remains in the system after cleaning. The condition of material balance of receipt and removal of the polluting substance described by the balance equation is considered fair.

$$m_{in}(t) = m_{out}(t) + m_{in}(t), t \in [0, T] \quad (1)$$

If we assume that the pollutant does not precipitate and is not deposited in the pipes of the system, and the volume of water in the system during $T$ changes slightly, then the balance equation for the concentration of the pollutant (mg / litres).

$$c_{in}(t) = \frac{w_1}{w_2} \cdot c_{out_2}(t) + \frac{w_2}{w_1} \cdot c_{out_2}(t) \quad (2)$$

where $w$ is the volume of the system, $w_1$ is the volume of the first flow, $w_2$ is the volume of the second flow, the function $c_{out}(t)$ depends on the characteristics of the cleaning device (filter area, etc.).

If the characteristics of the treatment device are considered to be given, the function of $c_{out}(t)$ can be determined empirically.

Let us consider different formulations of the problem of optimization of the treatment device on the example of the process of purification of circulating water.

Let the function $c_{out}(t) = \frac{1}{K} f(t)$, where $K = \frac{w_1}{w}$. It is believed that the system receives a substance whose concentration increases the concentration in the system (tank). Denote this function $C_{in}(t)$. Then the total concentration of the substance in the tank will be made up of $C_{in}(t)$ and the concentration of the substance remaining in the water after cleaning the piles $C_{out}(t)$.

Denote

$$C_{in}(t) - K_2 C_{out}(t) = U(t) \quad (3)$$

where $U(t)$ – control function, $K_2 = \frac{w_2}{w}$.

We assume that this function is from the class of piecewise continuous functions given on the segment $[0, T]$, $U(t) \in KC[0, T]$. Under the conditions of the problem, the concentration of the ingredient in the tank should not go out of the specified interval $[C_{min}, C_{max}]$, the condition must be satisfied.

$$C_{min} \leq U(t) \leq C_{max}, t \in [0, T] \quad (4)$$

Denote $x(t) = C_{in}(t)$. Then from equation (2) given (3) follows:

$$x(t) = \frac{1}{2} \cdot (U(t) + f(t)) \quad (5)$$

As an optimality criterion we choose the following functional:
where $C$ is some required concentration level in the tank, $C = \frac{1}{2} (C_{\min} + C_{\max})$, at any rate it is assumed that $C \in [C_{\min}, C_{\max}]$.

Then the optimal control problem can be formulated as follows: find such an optimal process $(x, u') \in KC[0,T] \times KC[0,T]$, which reports the minimum to the functional.

$$J(x,u') = \int_0^T (U(t) - C)^2 \, dt \to \min$$  \hspace{1cm} (6)

under constraints

$$x(t) = \frac{1}{2} (U(t) + f(t)), \hspace{1cm} (8)$$

$$C_{\min} \leq U(t) \leq C_{\max}, t \in [0,T] \hspace{1cm} (9)$$

The problem can be solved using the maximum principle [1]. Optimal function of incoming concentration:

$$x(t) = \frac{1}{2} (C + f(t)) \hspace{1cm} (10)$$

It is seen that the solution $(x, \bar{u})$ gives the functional a zero value, it is the absolute minimum of the problem.

Similarly, we can consider the following problem of optimal control of the treatment device in the circulating water system.

Let the function $c_{in}(t) = f_{in}(t)$, and you want to define the function:

$$K_1 \cdot C_{out}(t) = U(t) \hspace{1cm} (11)$$

Then the optimal control problem will have the following form:

find: $(u', x) \in KC[0,T] \times KC[0,T]$

$$J(x,u') = \int_0^T (x(t) + f_{out}(t) - C)^2 \, dt \to \min$$  \hspace{1cm} (12)

$x(t) = f_{out}(t) - U(t)$,

$$C_1 \leq U(t) \leq C_2, t \in [0,T]$$

where $C_1, C_2$ – property filters, $x(t) = K_2 \cdot C_{out}(t)$.
The problem has the following solution:

\[
U'(t) = \begin{cases} 
C_1, & 0 \leq t \leq T_1, \\
2f_0(t) - C, & T_1 \leq t \leq T_2, \\
C_2, & 0 \leq t \leq T 
\end{cases}
\]  

(13)

, where \( T_1, T_2 \) - control switching moments determined by the given \( f_0(t) \), \( C_1, C_2, C \), \( T \). If the data is such that the condition is satisfied:

\[
C_1 \leq 2f_0(t) - C, t \in [0,T], T_1 = 0, T_2 = T 
\]  

(14)

![Graphical interpretation of the problem solution](image)

**Figure 3.** Graphical interpretation of the problem solution

**CONCLUSION**

Thus, application of the offered technique allows to solve a problem of optimization of process of purification of the polluted waters for circulating systems of water consumption.

**REFERENCES**

[1] Melekhin A G 2006 *Purification of water solutions of detergents in the circulating water systems* (Perm: Publishing house of Perm National Research Polytechnic University).