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ANALYSIS AND IDENTIFICATION OF RISKS IN THE NORMAL WORK OF THERMAL POWER SYSTEMS

І.В. Уряднікова, В.Г. Лебедєв, В.М. Заплатинський. **Аналіз і визначення ризиків при штатній роботі теплоенергетичних систем.** Представлено аналіз і визначення ризиків, що виникають в системах водоочищення теплоенергетичних об'єктів при штатній роботі блоків цих систем. Встановлено, що при роботі систем водоочищення ТЕС і ТЕЦ виникають різноманітні техногенні ризики, які погіршують стан екологічної безпеки довкілля. Причинами цих ризиків є відмова блоків і елементів систем водоочищення, часткові відмови і нештатна робота систем водоочищення і ризики при штатній роботі систем водоочищення, як наслідок фізико-хімічних принципів, на яких вони працюють. Розрахунки і аналіз показують, що більша частина систем водоочищення може реалізовувати ризики ймовірності 0,03 з часом надходження неочищеної води на вихід системи 2,5…3 % від часу експлуатації.

Ключові слова: ризики, системи водоочищення, теплоенергетика.

И.В. Урядникова, В.Г. Лебедев, В.М. Заплатинский. **Анализ и определение рисков при штатной работе теплоэнергетических систем**. Представлены анализ и определение рисков, возникающих в системах водоочистки теплоэнергетических объектов при штатной работе блоков этих систем. Установлено, что при работе систем водоочистки ТЭС и ТЭЦ возникают различные техногенные риски, которые ухудшают состояние экологической безопасности окружающей среды. Причинами этих рисков является отказ блоков и элементов систем водоочистки, частичные отказы и нештатная работа систем водоочистки и риски при штатной работе систем водоочистки, как следствие физико-химических принципов, на которых они работают. Расчеты и анализ показывают, что большая часть систем водоочистки может реализовывать риски вероятностью 0,03 со временем поступления неочищенной воды на выход системы 2,5…3 % от времени эксплуатации.

Ключевые слова: риски, системы водоочистки, теплоэнергетика.

I.V. Uryadnikova, V.G. Lebedev, V.M. Zaplatynskyi. **Analysis and identification of risks in the normal work of thermal power systems.** The analysis and identification of risks arising in water treatment systems of power facilities at normal work of blocks of this presented of systems. It is found that when using water purification systems of thermal power plant the variety of man-made risks degrade ecological safety of environment. The reasons for these risks we faults of refusing units and elements of water purification systems, partial failure and abnormal operation of water purification systems and risks in normal work of water purification systems as a result of physical - chemical principles on which they work. Calculations and analysis show that most of the water treatment systems can implement risk probability of 0,03 with untreated water entry to the system outlet of 2,5...3 % of the operating time.

Keywords: water purification systems, heat and power engineering.

Introduction. Currently, the failures of the system of natural water purification are served by probabilistic calculation. However, we must examine the risks arising during the normal work of purification system through natural inaccuracy of the blocks and the inertia of the processes occurring in them.

The quality of treated water coming from the water treatment system, characterized by the content of her suspended and dissolved impurities is normalized by relevant standards. Since exactly specified characteristics can not endure, they are normalized respective limits, i.e, the largest or smallest permissible value of concentrations, and lower concentrations may be ideally zero. We can say that the water quality is normalized by asymmetric tolerance.

The errors that occur when using blocks of water purification systems. If all units of water treatment system work with some errors, they are summarized and provide the resulting amount of suspended and dissolved impurities. In this way, errors of all the blocks are transferred to the resulting value. Mathematically it can be expressed as [1]

$$\delta_{res} = \sum_{1}^{n} \delta_{err} \ , \tag{1}$$

where δ_{res} — the resulting fluctuations in concentration and δ_{err} — error that occurs at work of the n-th block of purification system.

In this case there is a problem of the determination of the permissible error of the constituent units of water treatment system, based on the set of the resulting fluctuations in value.

Assuming that all units operate with the same error, the permissible value of the error of each block will be

$$\delta_{block} = \frac{\delta_{res}}{n} \ . \tag{2}$$

Given this circumstance, it is necessary in each case to determine whether individual units providing the necessary degree of purification are technically realistic.

If we consider the system "clean boiler water", consisting of 6 units, then according to expression (2) the accuracy of maintaining water parameters, ensured by each unit must be

$$\delta_{block} = \frac{\delta_{res}}{6} \ . \tag{3}$$

If the output level of purification must be 0...10 mg / l, the quality of water that must be provided by each unit should be no more than 10/6 = 1,66 mg/l, which is difficult to obtain technically and economically costly.

All of the above said understanding just when to think that all the blocks of this system of water treatment will maintain the maximum allowable concentration value or the minimum value of concentration.

In practice, a combination of concentrations provided by blocks of the system, almost never happens in the largest or the lowest value. It gives the right to apply the law of probabilistic summation of concentrations, taking into account some acceptable risk. In this case, the expression (1) can be transformed according to [1], in the expression

$$\delta_{system} = t\sqrt{\sum_{1}^{m-1} \lambda^2 \delta_i^2} \ , \tag{4}$$

where δ_{system} — error in the system, δ_I — error of i-th block of the system, t — hazard ratio, λ — relative standard deviation, which characterizes the law of dispersion error of the i-th block. If conditionally put that error blocks of the same, then the expression (4) will be

$$\delta_{system} = t\sqrt{n\lambda^2\delta_i^2} \ , \tag{5}$$

whence

$$\delta_i = \frac{\delta_{system}}{t\lambda\sqrt{n}} \ . \tag{6}$$

Thus, given the probability of error maintain concentration intermediate blocks of the system and entering a valid risk factor can significantly reduce the accuracy of maintaining the concentration of each individual unit with virtually no violations precision maintain concentration throughout the whole system.

When failures of different blocks of purification systems, as well as their freelance work there are significant risks of a different nature, probability and magnitude of which is determined before.

However, this question of different risks is not exhaustive. An analysis of this issue shows, the risks may arise at normal work of purification system. This is due to the natural inertia of workflows, blocks of water treatment, with the change of input parameters of water entering the treatment, with a range of reagents and activity of some other reasons.

Analysis of environmental risks in the use of technology coagulation reagent and electro-coagulation. Review and analysis of the circumstances is only possible if the work processes that occur in the work of purification are regarded as a single system-level workflow, and this system can be either closed or open. Thus, managers need to consider not blocks of systems but their workflows.

This provides an opportunity to explore various technologies of purification and identify risks arising from their use.

Technology of reagent coagulation is widely used in power systems for cleaning rough and fine colloidal systems, and the size of dispersed particles varies quite widely from 10^{-9} to 10^{-4} m [2...4].

Purification of such water requires separation of liquid and solid phase by reagent technology, the method of consolidation of small particles in the aggregates under coagulants, flocculants, and mixtures thereof.

Low molecular inorganic or organic electrolytes that promote aggregation of particles are called coagulators. Salt, hydrolyzed and instituting the above electrolytes are called coagulants. Thous in most cases are sulfates, halides multivalent cations, mainly $Al_2(SO_4)_3$ and $FeSO_4$. Flocculants are organic and inorganic macromolecular compounds that contribute to the formation of aggregates by combining multiple particles using macromolecules adsorbed or chemically bound polymer and intensify the process formation of flakes. As flocculant polyacrylamide (PAA)is used.

In this way, the essence of technology of purification by method of coagulation reagent colloidally dispersed systems is to reduce the stability of dispersed systems by aggregation of particles of the dispersed phase under the action of coagulants and flocculants followed by separation of solid and liquid phases by water upholding, filter, and by several other methods.

Note that dispersed systems are divided into lyophilic and lyophobic systems.

The former are characterized by strong intermolecular interaction of particles of the dispersed phase with the environment (water) and high thermodynamic stability of the system.

The latter are characterized by a large binding energy within the dispersed phase, well above the energy of interaction with the environment. For these systems distinguish sedimentation resistance to the forces of gravity and aggregate stability that characterizes the resistance of particles sticking.

Workflows of technology of coagulation reagent can be represented by the following links [2, 3].
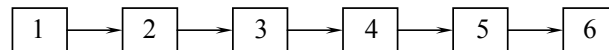
Fig.1. Chain of workflow reagent coagulation: 1 — coagulant dosage; 2 — growth activity of coagulant in water that is purified; 3 — process of coagulation; 4 — deposition process of cereal that have coagulated; 5 — filtration purified solution, 6 — change the water concentration in the waters

1 — fuse casing. Valve opens and after a while comes a coagulant in water that is purified. In terms of dynamic properties dispenser represents a delayed link, the output value of which exactly replicates the input value, but with some delay in time. The time delay depends on the structure and mode of dosing. Thus equation dispenser can be explained as an expression [5...10]:

$$m_{out}(t) = m_{in}(t - \tau), \tag{7}$$

where m_{out} and m_{in} — are respectively output and input weight coagulant, τ — time lag.

The transfer function of this link, which is the initial value to the input, as represented in operator form is

$$W(p) = e^{-p\tau}, \tag{8}$$

where p — a complex variable used in Laplace transform.

In this way, we can say that the process of coagulation reagent starts with some delay.

2 — The process of increasing coagulant activity. As shown in [2...4], 100 % coagulant activity does not occur immediately, but after some time.

The equation of this process is:

$$T\frac{dA_{out}}{dt} + A_{out} = kA_{in}, \tag{9}$$

where T — time constant of the process, A — coagulant activity (0...1), k — factor of proportionality or gain level.

The transfer function is equal to

$$W_1(p) = \frac{k}{Tp+1}.$$ (10)

In this way the process of increasing coagulant activity comply with the law changes the output value of aperiodic link.

3 — The process of coagulation is described by Smoluchowski [2...4], which has the form

$$\frac{dK_{out}}{dt} = -\frac{2}{3}\frac{RT\rho K_{in}^2}{\eta r},$$ (11)

where K_{out} — current concentration of coagulated impurities, K_{in} — coagulated maximum concentration of impurities, R — radius of the sphere of attraction of particles, T — ambient temperature, t — current time, η — dynamic viscosity of the medium, r — radius of the particle, ρ — distance between particles.

Equation 11 can be represented as follows

$$\frac{dK_{out}}{dt} = -k_1 K_{in}^2,$$ (12)

whence the transfer function is

$$W_2(p) = \frac{K(p)}{K^2(p)} - \frac{-m}{p}.$$ (13)

4 — The process of deposition of coagulated flakes

Increased concentrations of sediment in time can be described by the equation [2...4]

$$T_2 \frac{dK_{out}}{dt} + K_{out} = k_2 K_{in}.$$ (14)

In this case, the transfer function is

$$W_3(p) = \frac{k_2}{T_2 p + 1}.$$ (15)

Final cleaning process is completed filtration equation which has the form [2]:

$$\frac{dV}{Sdt} = \frac{\Delta P}{\mu(R_{os} + R_{per})},$$ (16)

where V — volume of leachate, S — filtering surface area, ΔP — pressure difference before and after the filter, μ — viscosity of filtrate, R_{os} — resistance sediment, R_{per} — resistance filtering septum.

The transfer function is

$$W_4(p) = \frac{z}{p}.$$ (17)

The final link in the process of purification is some water users, which consumes a certain weight of purified water and contains its defined scope. This link can be represented by some cisterns. Changing the concentration of impurities in the water catchments in this dependence can be expressed:

$$K(t) = \frac{(V - vt)K_1 + vtK_2}{V},$$ (18)

where V — volume of water in the receiving waters, v — filtration rate, K_1 — initial concentration of impurities in the water that comes to cleaning, K_2 — the concentration of impurities in the water after their deposition, t — current time.

The transfer function of the process water treatment using coagulation technology will be [5...10]
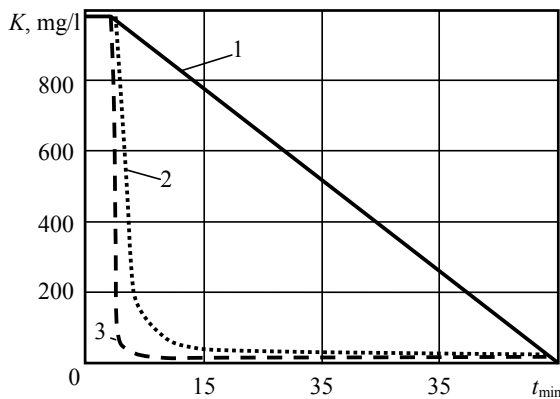
$$W(PV) = W(p)W1(p)W2(p)W3(p)W4(p).$$ (19)

Fig. 2. Changing concentrations of contaminants during the process of water purification technology coagulation reagent: 3 — change in concentration of not coagulated particles dispersed impurities; 2 — change in concentration of particulate impurities in the water that is purified, the deposition of coagulated particles; 1 — change in the concentration of water purified in water intake; t — current time in minutes.

To study the dynamics of the process using mathematical modeling, it is necessary to solve the following system of equations, given the fact that the output of the previous level is an input to the next.

$$T\frac{dA_{out}}{dt} + A_{out} = kA_{in},$$

$$\frac{dK_{out}}{dt} = -\frac{2}{3}\frac{RT\rho K_{in}^2}{\eta r},$$

$$T_2\frac{dK_{out}}{dt} + K_{out} = k_2 K_{in}, \qquad (20)$$

$$\frac{dV}{Sdt} = \frac{\Delta P}{\mu(R_{os} + R_{per})},$$

$$K_{(t)} = \frac{(V - vt)K_1 + vtK_2}{V}.$$

In solving this system one should take into account the fact that there is some delay time τ, provided belated link - dispenser.

Dynamic characteristics of the process can be studied also by transfer functions (19), using the theory of automatic control [5...8]. However, the solution of (20) gives a visual representation of the dynamics of the process and gives a more realistic representation of change in the concentration of pollutants in time. This is important because it gives the opportunity to have an idea of what kind of part-time work of wastewater treatment system that works in standard mode, the consumer receives a water that was not constantly purified.

Currently, the solution of (20) is much easier, because now a powerful mathematical attachments MATKAD and MATLAB, enabling to obtain a numerical and analytical solutions.

Accepted according to studies [2, 11] to K_1=1000 mg/l, T=0,5 min, T=2 min, filtering surface area of the filter S=1 m^2, speed of liquid after filter 8,32 l/min, V = 0,5 m^3. Other values are also accepted according to the above-mentioned works. As a result, we obtain the mathematical modeling of the dynamics of the process of changing the concentrations of contaminants in water treatment by coagulation technology, as shown in Figure 2.

As seen from the results of mathematical modeling, the change in concentration in the reagent container is 5...7 min. This means that whenever there is a change of concentration of particulate impurities at the inlet a corresponding change coagulant dose is adjusted for at least 5 minutes, which will be 41.6 liters of untreated water. At sufficiently frequent change of concentration at the inlet or by changing the coagulant activity, the proportion of contaminated water by installing water purification work in normal mode, can be quite large.

As shown by the result of simulation, the change in concentration of water in the receiving water is much slower, to which attention is drawn in [6, 7].

The results obtained by changing the concentration of $K_4(\tau)$, can be taken as the basis for calculating the risk, since an increase in water intake is in proportion to increasing filtration area and the number of filters.

Conclusions. 1. At sufficiently frequent change of concentration at the inlet or by changing the activity of workflows water treatment, the proportion of contaminated water by installing water purification work in normal mode, can be quite large and exceed commonly accepted allowable value of 1...2 %, which is associated with the natural inertia of workflows .

2. Change of the water concentration in the receiving water is much slower than the actual output settings for any method of water purification. Results on changing of the concentration of water in the receiving water, can be taken as the basis for calculating the risk, since an increase in water intake, significantly changing the dynamic characteristics of the system water purification.

3. Based on the simulation results of the system reagent coagulation and electrocoagulation, shows that the full-time work system, with very frequent changes of concentration at the inlet (which in most cases correspond to reality) the risk of obtaining of not purified water is significant.

4. For a system reagent coagulation and electrocoagulation with an average productivity of 40 m^3, the risk of contaminated water at the outlet of the system is approximately 28242 m^3 per year, i.e. 0.08. This is a considerable amount that must be taken into account to evaluate the economic, social and environmental risks because it exceeds 0.03 risk usually allowed at work.

5. At sufficiently frequent change of water concentration at the inlet particle contaminated water when working with ionite purification installation in standard mode, can be quite large, which is associated with the natural essence of business processes with ionite in the filter.

6. Summarizing the results of the analysis of different methods of water purification and water treatment it must be recognized that even in normal mode, with some perturbations in systems of contaminated water can enter the limits prescribed by regulatory requirements.

7. When using water purification systems of thermal power plant we have a variety of man-made risks that degrade ecological safety of environment. The reasons for these risks are faults of units and elements of the water purification systems, partial failure and abnormal operation of water purification systems and risks in normal work of water purification systems as a result of physical-chemical principles on which they work. These developments are likely compatible. The total probability of these events is derived according to the laws of probability theory. Calculations and analysis show that at the present time, most of the water treatment systems can implement risk probability of 0,03 with untreated water entry to the untreated water entry to the system outlet of 2,5...3 % of the operating time.

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