Development of a mathematical model of a recycling cooling system of a thermal power plant

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Abstract. In thermal power plants in Uzbekistan, the drainless recycling cooling system is widespread, in which water of the most favorable and constant quality and heated in the condenser turbines are used in the water treatment plant thermal power plant. Since the recycling cooling system uses technical raw water, low solubility deposits (scale) are formed on heat exchange surfaces in turbine capacitors. It is believed that the cause of precipitation is the concentration of low soluble water components by evaporation of water in cooling towers. Due to the low thermal conductivity of the deposits formed on the heat exchange surface of the capacitors, the temperature pressure increases. As is known from the scientific and technical literature, the pressure in the turbine capacitors depends on the contamination of the cooling surface. Because of this, the vacuum worsens. The deterioration of the vacuum leads to an over-consumption of steam. Thus, the aim of this work is to increase the operational efficiency of the recycling cooling system of the thermal power plant.

1. Introduction

Three types of technical water supply are mainly used in power plants: revolving, direct and combined [1]. The most common negotiable. In revolving systems is mandatory the presence of a water cooler. Its functions can be performed by cooling water, cooling towers or spray pools. The water supply system with water cooler is the most common in the existing condensation plants. In this system, the main building of the power plant is usually located near the shore of the reservoir, and the circulation pumps in the shore pump.

Cooling in the water cooler occurs as a result of contact between water and air when it moves both within the water area and in the height of the water layer. The heat supplied in large quantities with heating in the condensers is discharged mainly by evaporative cooling. Such cooling significantly increases the heat exchange rate between air and water [2, 3]. The water temperature may be below the ambient temperature. This difference increases with decreasing relative humidity.

The technical water supply scheme with cooling towers usually includes a central pumping station located at the permanent end of the engine room of the main building of thermal power plants (TPP). After the cooling water is cooled, it flows through reinforced concrete channels to the inlet of the circulation pumps. Their installation ensures work under the bay. In the pumping stations of modern large thermal power plants with cooling towers are used both conventional centrifugal and axial vertical pumps [1, 2, 3].

2. Methods

The main requirements for the quality of the cooling water are that it has a temperature that ensures the required vacuum depth in the condenser, does not recover when heating the formation in the cooling system of mineral deposits and biological fountains, as well as corrosion of equipment and pipelines. Naturally, at such high costs of water, cooling capacitors, oil and gas coolers, it is inappropriate to ask for its thorough cleaning with the removal of all impurities prone to the formation of sediments and corrosion on the materials of the cooling system. In [4-9] a method is proposed, which allows to calculate sufficiently accurately the change of salt composition of circulating water in circulating cooling systems.

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In cooling towers or spray pools, the return water temperature is reduced by evaporation of a part of the heated water in the water condenser and convective heat exchange when in contact with air, then the water is returned to the heat exchangers-capacitors (pic. 1). In cooling towers part of circulating (cooling) water is lost due to drip drift $\left(P_{ун} = 0,05 - 3,5\%\right)$ and evaporation ($P_{исп} = 1,0 - 1,5\%$).
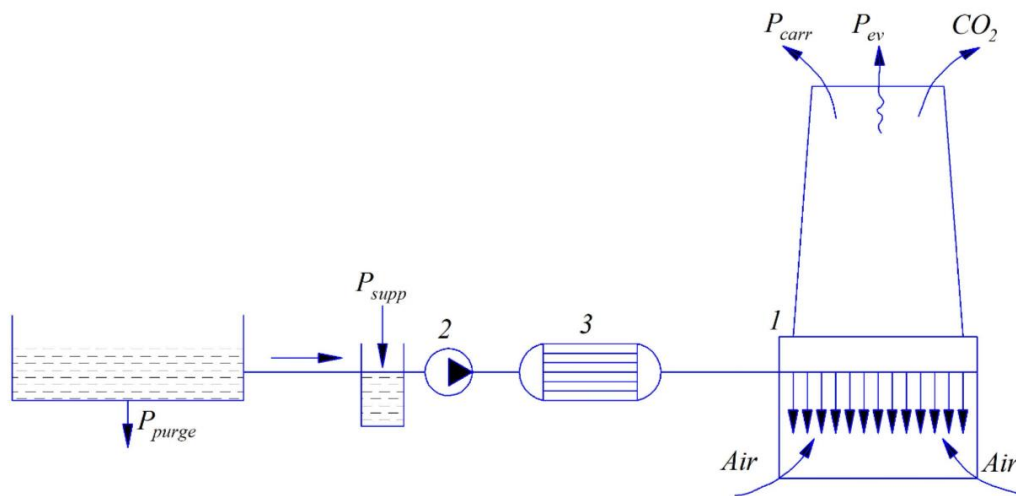

Fig. 1. Cooling circuit with cooling tower: 1-cooling tower; 2-circulating pump; 3-capacitor; P_{vap}, P_{dr} – water loss in the cooling tower for evaporation and drift; P_{sw} – swilling; P_{add} – adding fresh water to the system.

The evaporated moisture is pure water, so by evaporation, the salt content of the water in the revolving system increases [1-3]. The salt is regulated by water exchange by flushing the system $P_{прод}$. The observed losses are compensated by adding water to the system:

$$P_{add} = P_{vap} + P_{dr} + P_{sw}. \tag{1}$$

For salts that do not form hard-soluble compounds, when the water in the cooling system is heated, the mass balance in the established mode is recorded as

$$C_{add} \cdot P_{add} = C_{circ} \cdot (P_{dr} + P_{sw}) = C_{circ} \cdot \left(P_{add} - P_{vap}\right), \tag{2}$$

where C_{circ}, C_{add} – concentration of salts (ionized impurities) in additive and circulating waters.

From (2) follows, relation $\frac{C_{circ}}{C_{add}}$, called concentration factor K_K, is determined by the value of the circulation water loss with purge and drip drift (table. 1). Also K_K are called the evaporation factor [9, 11].

The reduction of the flushing value leads to an increase in the concentration multiplicity and, consequently, to a significant increase in the saline content of the circulation water. When $P_{sw} = 0$ indicator K_K is determined by the water loss in the system due to drip drift.

Table 1. Concentration coefficient depends on blowing of the revolving cooling system

Flushing, %	Cooling towers with drop catchers Cooling tower without drop catchers	Cooling towers with drop catchers Cooling tower without drop catchers
0	41,0	4,00
0,5	3,68	2,50
1,0	2,42	2,00
2,0	1,73	1,60
4,0	1,37	1,33
6,0	1,30	1,28

In addition to the concentration of soluble salts in the recycling cooling system, the concentration of hardness salts and hydrocarbons increases in the same multiplicity. The process of formation of carbonate sediments in heat

exchangers [2] will be determined by the shift of carbon dioxide equilibrium during water heating [11-14]. Hydrolysis intensifies as water temperature rises in the recycling cooling system HCO_3^-, which is characterized by the

$$2HCO_3^- \Leftrightarrow CO_3^{2-} + CO_2 + H_2O \qquad (3)$$
$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \downarrow. \qquad (4)$$
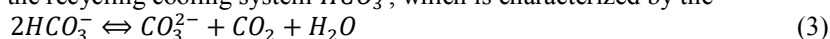
Shift of the right reaction (3), i.e. decay of ions HCO_3^- and the formation CO_3^{2-}, The loss of carbon dioxide produced by hydrolysis in the cooling tower [5, 6] (similar to the decarbonizer process) also contributes. These factors lead to the possibility of separation on the heat exchange surface of the sediments $CaCO_3$ (water overload (WO) $CaCO_3$), i.e. loss of coolant water stability [7-11] when the product of interacting components exceeds $WO_{CaCO_3} < a_{Ca^{2+}} \cdot a_{CO_3^{2-}}$ [14-19]. Calcium sulphate has a relatively high solubility at $t = 20 - 40\ °C$ (around $1800\ \frac{mg}{dm^3}$), therefore, it is rare in low temperature sediments.

Since the thermal conductivity of the calcium sediments is an order of magnitude less than the thermal conductivity of the metal of the condenser tubes, as the thickness of the scale increases, the vapour condensation temperature increases and the vacuum in the condenser decreases. The deterioration of the vacuum by 1% requires an increase in the steam consumption by 1.4% to maintain the nominal capacity of the turbocharger. Thus, sediments in the revolving cooling system (revolving cooling system) cause significant fuel burning during power generation.

Despite this fact, and the fact that in a rotating cooling system with cooling towers, the temperature of the cooling water at the inlet to the condensers is higher than in direct current systems with reservoirs, the use of cooling towers allowed to dramatically reduce the discharge of heated water into watercourses and water bodies, preventing their «heat» poisoning. Moreover, these revolving systems are only acceptable under conditions of limited water flow.

Mathematical model for calculation of material balance of circulating cooling system

Here and further, by recycling cooling system we mean part of the recycling cooling system from the cooling water side, including cooling water and the boundaries of the solid and gas phase. Simulating a real revolving cooling system and determining the material balance presents some difficulties. First of all, it is due to the large volume of the system (the mass of water in the revolving cooling system). In addition, the water volume (mass) of the system is variable over time and can both increase and decrease depending on the ratio of inputs and outputs. Water and air flows themselves (m_i, i – sequence flow index) and concentrations of substances contained therein (concentrationsя j-th independent components – c_j) changing in a complex, unpredictable way over time. Under such conditions, calculation of the known equations (1-4) is either not possible or leads to large errors in which the results of calculations are devoid of physical sense.

As part of the system approach, the TPP recycling system should be considered as a flow, continuous system with non-stationary operation. Thermal mode of operation - intermediate. However, given the long length of the system, the small temperature interval, and therefore the very small temperature gradient, for most of the revolving cooling system, it is possible to adopt the thermal regime as quasi-thermal isothermal. The revolving cooling system is a closed system in which the apparatus and piping circulate water by a mixing device - pumps. From a thermodynamic point of view, a revolving cooling system is an open material system, because there is mass and heat exchange with the environment. Chemical reactions and physico-chemical processes take place in the revolving cooling system. Reactions occur in all phases - liquid (equilibrium chemical reactions), solid (low solubility deposits, internal corrosion and corrosion product dissolution) and gas (volatile air mass exchange). For such cases, the equations of material and thermal balances are given only in general terms (in the form of partial differential equations). To make them suitable for engineering calculations, a detailed review of the specific system is needed to determine the permissible simplifications that allow for the simplest but adequate description of the system.

In general, the flow diagram and structure of the TPP revolving cooling system for calculating the material balance can be presented as shown in Figure 2. Further simplification of the scheme is not possible.

In the revolving cooling system, the two main material inputs are additive water (from p. Chirchik, $m_a, c_{j,a}$) and air flows to cooling towers ($m_в, \varphi$ – humidity). There is still a small return of sludge chemical water treatment, which in the first approximation can be neglected, or considered permanent (approximately $2,2\ \frac{m^3}{hour}$). Output flows are represented by water consumption in the chemical workshop at the water treatment plant («raw» water, $m_{хц}, c_{j,ц}$), evaporation of water in cooling towers (m_{vap}), droplet drift of circulating water in cooling towers $(m_{r.dr}, c_{j,c})$ и hydrocarbon drift with air flow (m_{CO_2}). There is still an intermittent time discharge of circulating water to the

prominent sewerage (due to overflow of water in cooling towers and leaks from pipelines and TPP equipment) and intake of circulating (technical) water to the needs of workshops (TW).
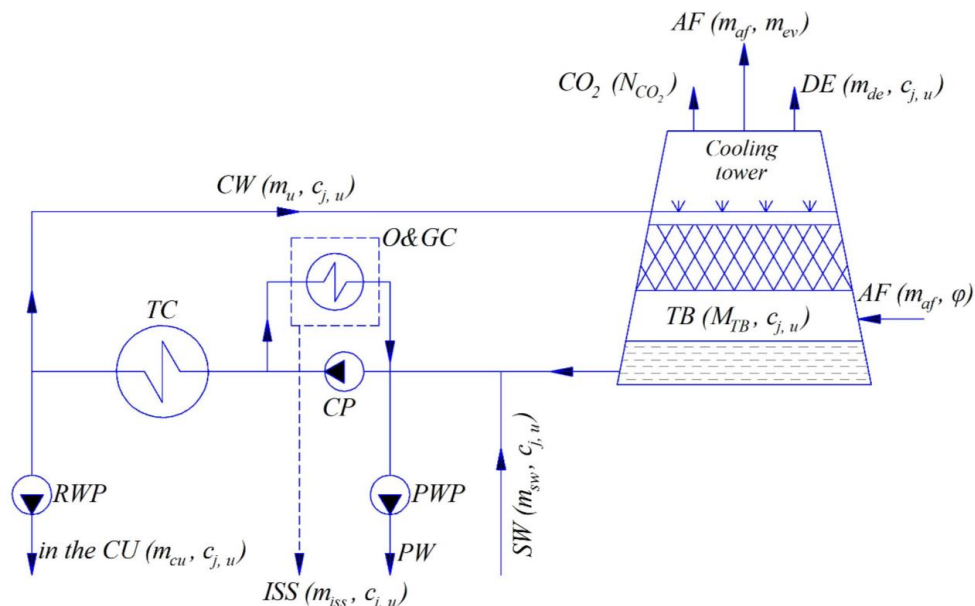

Fig. 2. Schematic diagram of the revolving cooling system of the thermal power plant for calculating the material balance: Symbols: CT – cooling tower; TC – cooling tower's cup; CP – circulation pump; TC – turbine condensers; RWP – raw water pump; PWP – process water pump; AW – added water; CW – circulating water; O&GC – oil gas coolers and other heat exchangers, incl. purification plants included; B – air flow; DD – drip drift; ISD – industrial storm drain. In parentheses is the number of units.

3. Results

Derivation of equations for calculation of material balance of circulating cooling system of thermal power plant. First of all, let's make acceptable simplifications and define limitations. In particular, the hydrodynamic situation or complexity of the flow structure is of paramount importance. Logically, a combined model constructed as a collection of cells of different types and sizes connected in series and in parallel is suitable as a model for a revolving cooling system.
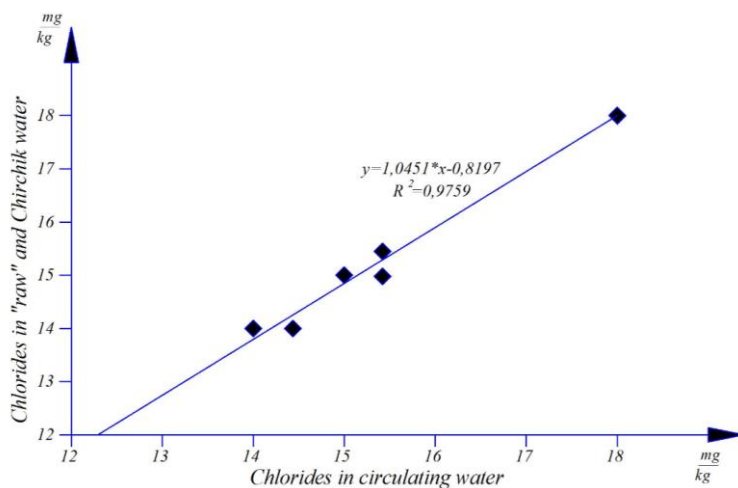

Fig. 3. Chloride concentration in different parts of the TPP recycling cooling system and in the Volga water additive at the time τ_i during the experiment in July 2022. Average concentration of chlorides in the additional water of the $- 12,3 \frac{mg}{kg}$
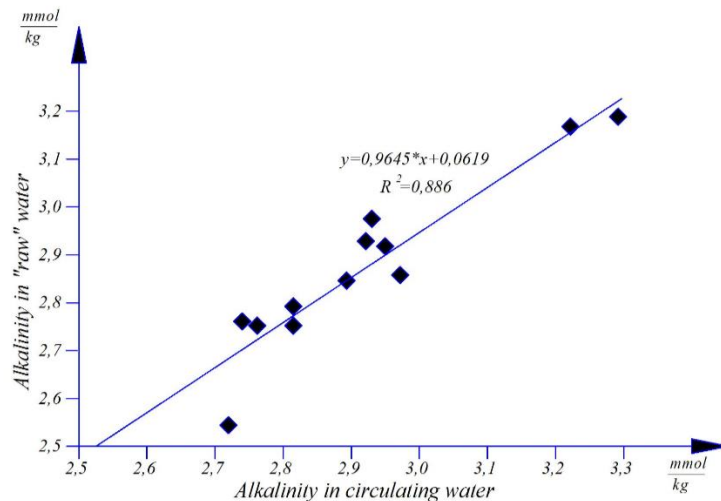
Fig. 4. Total alkalinity in different parts of the TPP revolving cooling system at time τ_i during the experiment in July 2022. Total alkalinity of the additive chirchic water – $2,305\ \frac{mmol}{кг}$

Direct experiments were conducted to determine the hydrodynamic situation in the revolving cooling system. During scheduled experiments in May and July 2022, the chemical composition of the water was determined twice a day in different parts of the revolving cooling system (at 10:00 and 14:00). For reasons of probable maximal differences, the control points were chosen - (1) water at the outlet from the reverse cooling system («raw» water to the water treatment plant); (2) water in the cooling tower (circods) and (3) water in a gravity well (circods). Furthermore, the control points (1) and (2) are separated by cooling towers, where processes occur that maximally change the composition of water (evaporation and volatilization CO_2), and points (1) and (2) – circulation pump and additive water input.
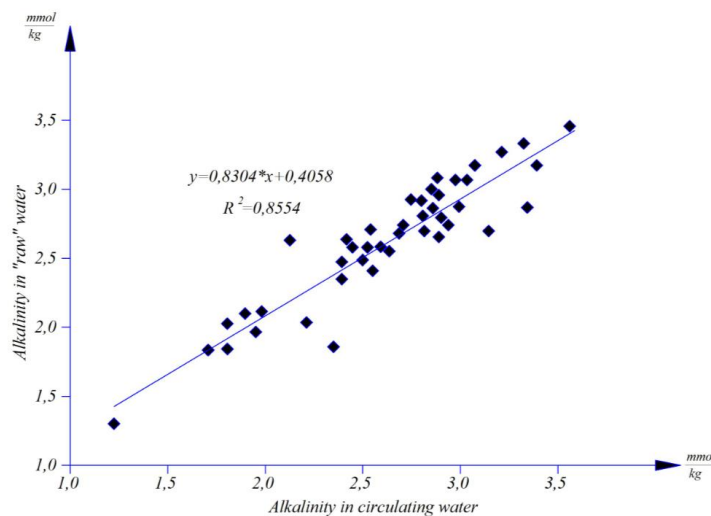

Fig. 5. Ratio of total alkalinity (average monthly values) in circods and «raw» water in the recycling cooling system of thermal power plants in 2020 - 2022.

Statistical analysis of dissolved component concentrations in the output stream ("raw" water for water treatment plant) and different points of the revolving cooling system at the time τ_i does not show a valid difference (fig. 3 and 4). This also applies to substances knowingly active in chemical reactions and physico-chemical processes. Their content reflects the total alkalinity of water. For a certain point in time, the alkalinity in different parts of the revolving cooling system is the same within the error of experience and is reliably different from the alkalinity of the additive water.

This pattern is typical for other periods of work. On picture A comparison of the average monthly total alkalinity over the last five years is presented.Summarizing the above, it is possible to write for the revolving cooling system. System type - flow (continuous), closed, open material; flow structure - ideal mix; operation mode - non-stationary, thermal operation - isothermal (quasi-static). Chemical, biochemical and physico-chemical processes in the system are non-stationary.

$m_i, c_j \neq const$. The fluxes and concentrations of components(s) in flows are variable over time, i.e. $(m_i)_\tau, (c_j)_\tau = f(\tau)$

$M_p, M_{чг} \neq const$. Water masses in the system and parts thereof are variable in time $- (M_p)_\tau, (M_{tc})_\tau = f(\tau)$

The water mass balance of the revolving cooling system is recorded as:

$$(m_a)_\tau \cdot d\tau - (m_{vap})_\tau \cdot d\tau - (m_{dr})_\tau \cdot d\tau - (m_{ch.sh})_\tau \cdot d\tau - (m_{isd})_\tau \cdot d\tau = d(M_p)_\tau. \quad (5)$$

Balance for j-th not developing or transitioning to other phases:

$$(m_a)_\tau \cdot (c_{j,a})_\tau \cdot d\tau - (m_{dr})_\tau \cdot (c_{j,c})_\tau \cdot d\tau - (m_{ch.sh})_\tau \cdot d(c_{j,ch.sh})_\tau \cdot \tau - (m_{isd})_\tau \cdot (c_{j,c})_\tau \cdot d\tau = (M_p)_\tau \cdot d(c_{j,c})_\tau. \quad (6)$$

For the rest of components:

$$(m_a)_\tau \cdot (c_{j,a})_\tau \cdot d\tau = (m_{dr})_\tau \cdot (c_{j,c})_\tau \cdot d\tau + (m_{ch.sh})_\tau \cdot d(c_{j,ch.sh})_\tau \cdot \tau + (m_{isd})_\tau \cdot (c_{j,c})_\tau \cdot d\tau + (M_p)_\tau \cdot d(c)_\tau + dN_{j,c}. \quad (7)$$

where $N_{j,ц}$ – The number of components that have been transformed into other components as a result of chemical reactions or have changed phases from circulating water.

So, we get the system from $m + 1$ simple differential equations, which is a model that describes the movement, accumulation and transformation of components and flows in a revolving cooling system. Equations 5 - 7 can be represented in the form of a certain integral:

$$\int_{\tau_1}^{\tau_2}(m_a)_\tau \cdot (c_{j,a})_\tau \cdot d\tau - \int_{\tau_1}^{\tau_2}(m_{dr})_\tau \cdot (c_{j,c})_\tau \cdot d\tau - \int_{\tau_1}^{\tau_2}(m_{ch.sh})_\tau \cdot d(c_{j,ch.sh})_\tau \cdot \tau = \int_{c_{j,c1}}^{c_{j,c2}}(M_p)_\tau \cdot d(c_{j,c})_\tau + \int_{N_{j,c1}}^{N_{j,c2}} dN_{j,c} \quad (8)$$

boundary conditions: at $\tau = \tau_1$, $c_{j,c} = c_{j,c1}$, $N_{j,c} = N_{j,c1}$, $M_p = M_{p1}$, $\tau = \tau_2$, $c_{j,c} = c_{j,c2}$, $N_{j,c} = N_{j,c2}$, $M_p = M_{p2}$.

In real conditions the values of additive water consumption, water consumption in the chemical plant, the concentration of substances in the additive, circulating and «raw» (comes to the chemical plant from the recycling system) water are known. These are model input parameters. The evaporation, drip drift and other leaks and the amount of precipitation generated are unknown or need to be clarified.

Equations of type 8 can be resolved explicitly by quadrature with respect to the mean values of parameters for the time interval Ax. The equations were approximated by a system of algebraic equations.

Joint solution of integral forms of equations 5 and 6 for components not involved in chemical transformations and inter-phase transitions allows finding water costs for evaporation and leakage (drip drift, flow rate in ISD and for the needs of the workshops - technical water consumption).

$$\bar{m}_{dr} = \bar{m}_a \cdot \frac{\bar{c}_{j,a}}{\bar{c}_{j,c}} - \frac{\bar{M}_p}{\bar{c}_{j,c}} \cdot \frac{\Delta c_{j,c}}{\Delta \tau} \quad (9)$$

$$m_{dr} = m_{dd} + m_{ch.sh} + m_{isd} + m_{sw} \quad (10)$$

$$\bar{m}_{vap} = \bar{m}_a - m_{dr} - \frac{\Delta M_p}{\Delta \tau}. \quad (11)$$

Additional consideration of the balance equations for the remaining components (sediment and carbon dioxide) allows determination of precipitation rates in the revolving cooling and drift system CO_2:

$$\frac{\Delta N_{j,c}}{\Delta \tau} = \bar{m}_a \cdot \bar{c}_j, - \bar{m}_{dr} \cdot \bar{c}_{j,c} - \bar{M}_p \cdot \frac{\Delta c_{j,c}}{\Delta \tau}. \quad (12)$$

Top line means the average value of the parameter over a period of time

The system of algebraic equations 10-12 was further used to calculate the material balance of the TPP recycling system by processing a data set of flow volume values and concentrations of substances in flows.

Further, in order to determine the dependence of the water concentration of the revolving cooling system on time, the original system of differential equations 5-6 was allowed for non-contracting components. Let's think of the basic equation as:

$$m_a \cdot c_{j,a} \cdot d\tau - m_{dr} \cdot c_{j,c} \cdot d\tau = M_p \cdot dc_{j,c} + dN_{j,c}, \quad (13)$$

where m_{dr} – all types of treatment (leaks) circulating water in liquid form. Consequently $m_y + \frac{\Delta M}{\Delta \tau} = m_a - m_{vap}$. Note that for non-participants component $dN_j = 0$ and designate $c_{j,c} = x$. Then after conversion, equation 13 is:

$$\frac{m_a}{m_a - m_{vap}} \cdot c_{j,д} \cdot d\tau - x \cdot d\tau = \frac{M_p}{m_a - m_{vap}} \cdot dx \tag{14}$$

or

$$\left(\frac{m_a}{m_a - m_{vap}} \cdot c_{j,a} - x\right) \cdot d\tau = \frac{M_p}{m_a - m_{vap}} \cdot dx \tag{15}$$

After separating the variables, we integrate under the following boundary conditions: $\tau_1, c_{j,c} = c_{j,c1}$; at $\tau_2, c_{j,c} = c_{j,c2}$:

$$\int_{\tau_1}^{\tau_2} \frac{m_д - m_{vap}}{M_p} \cdot d\tau = \int_{c_{j,c1}}^{c_{j,c2}} \frac{dx}{\left(\frac{m_a}{m_a - m_{vap}} \cdot c_{j,a} - x\right)}. \tag{16}$$

Presented integral expression we can solve only approximatively, т.к. $m_д$, $m_{исп}$ and M_p time-dependent, but the type of dependency is unknown to us. For example, by quadraturing, you can take their averages over a selected period of time. Then the integral is solved analytically. As a result, we get:

$$\frac{\bar{m}_a - \bar{m}_{vap}}{\bar{M}_p} \cdot d\tau = \ln\left(\frac{\bar{\varphi} \cdot c_{j,a} - c_{j,c1}}{\bar{\varphi} \cdot c_{j,a} - c_{j,c2}}\right), \tag{17}$$

где $\frac{\bar{m}_{vap} + \bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}}{\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}} = \frac{\bar{m}_a}{\bar{m}_a - \bar{m}_{vap}} = \frac{\bar{m}_a}{\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}} = \bar{\varphi}$ – average evaporation rate (K_{dr}) за период времени $\Delta \tau$. Here and further the change in the mass of water in the circulating cooling system refers to the unit of time $\left(\Delta M_p = \frac{\Delta M_p}{\Delta \tau}\right)$. Unlike the equations in the literature (1-4), this ratio is not equal to the concentration ratio, so $\varphi \neq K_{con}$; $K_{con} = \frac{c_{j,c}}{c_{j,a}}$. Equation 17 can be represented as an exponent:

$$\frac{\bar{\varphi} \cdot c_{j,a} - c_{j,c1}}{\bar{\varphi} \cdot c_{j,a} - c_{j,c2}} = e^{-\left(\frac{\bar{m}_a - \bar{m}_{vap}}{\bar{M}_p}\right) \cdot \Delta \tau}. \tag{18}$$

By transforming equation (18), the concentration of components(s) in the water of the circulating cooling system can be related to time, flow rate and initial concentrations of substances in flows:

$$c_{j,c2} = \frac{\bar{m}_a}{\bar{m}_{dr} + \Delta M_p} \cdot c_{j,a} \cdot \left(1 - e^{-\left(\frac{\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}}{\bar{M}_p}\right)}\right) + c_{j,c1} \cdot e^{-\left(\frac{\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}}{\bar{M}_p}\right)}. \tag{19}$$

For the concentration ratio this dependence will be:

$$K_{con2} = \frac{c_{j,c2}}{c_{j,a}} = \frac{\bar{m}_a}{\bar{m}_{dr} + \Delta M_p} \cdot \left(1 - e^{-\left(\frac{\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}}{\bar{M}_p}\right)}\right) + \frac{c_{j,c1}}{c_{j,a}} \cdot e^{-\left(\frac{\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}}{\bar{M}_p}\right)}. \tag{20}$$

Accept that, $\frac{\Delta M_p}{\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}} = \bar{\tau}$ – average residence time of additive water in the revolving cooling system, а $\frac{\bar{m}_{dr}}{\bar{M}_p} \cdot \Delta \tau = \frac{\Delta \tau}{\tau} = \gamma$ – frequency of water renewal (replacement) in the revolving cooling system. Then the concentration ratio at the end of the time interval (for $\tau = \tau_2$) will be:

$$K_{con2} = \bar{\varphi} \cdot (1 - e^{-\gamma}) + K_{con1} \cdot e^{-\gamma}, \tag{21}$$

where $K_{к1}$ – concentration ratio at the beginning of the time interval (for $\tau = \tau_1$). Time within which circulation water changes (from $c_{j,c1}$ to $c_{j,c2}$) can be determined by equation:

$$\Delta \tau = \frac{\bar{M}_p}{\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}} \cdot \ln\left[\frac{\bar{m}_a \cdot \bar{c}_{j,a} - \left(\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}\right) \cdot c_{j,c1}}{\bar{m}_a \cdot \bar{c}_{j,a} - \left(\bar{m}_{dr} + \frac{\Delta M_p}{\Delta \tau}\right) \cdot c_{j,c2}}\right], \tag{22}$$

the same for the time concentration factor will be:

$$\Delta \tau = \bar{\tau} \cdot \ln\left(\frac{\bar{\varphi} - K_{con1}}{\bar{\varphi} - K_{con2}}\right). \tag{23}$$

By converting equation 23, one can express the time when the water is replaced by the recycling cooling system by the additive water. It follows from the ideal mixing condition that there is no complete replacement of the circulating water with the additive water in continuous operation. We can only talk about partial water replacement, for example, 50%, 90%, 99%. If you specify the share of water replacement of the revolving cooling system with additive –

$\alpha(\alpha \leq 0 \leq 1)$, then, taking into account the concentration of water in the revolving cooling system, the time for the replacement of water by $\alpha \cdot 100\%$ (τ_α) will be:

$$\tau_\alpha = \bar{\tau} \cdot \ln\left(\frac{1}{1-\alpha}\right). \tag{24}$$

Similarly, it is possible to allow a fraction of the remaining unused water to the recycling cooling system. If $1 - \alpha = \beta$ – percentage of remaining water not replaced, then

$$\tau_\beta = \bar{\tau} \cdot \ln\left(\frac{1}{\beta}\right) = -\bar{\tau} \cdot \ln\beta. \tag{25}$$

and

$$\beta = e^{-\frac{\tau_\beta}{\bar{\tau}}}. \tag{26}$$

If you replace absolute values of flows by their share $(p_i, \%)$ relatively circulating water $m_c - \frac{m_a \cdot 100}{m_c} = p_a; \frac{m_{dr} \cdot 100}{m_c} = p_{dr}; \frac{m_{vap} \cdot 100}{m_c} = p_{vap}$, then the main indicators in equations 19-27 will depend on the percentage of flows, and $\bar{\tau}$ will make sense the average water turnover time in the revolving cooling system. If accept that:

    1. system operating time is very long $(\tau \to \infty)$;

    2. system mass is negligible $\left(M_p = 0\right)$;

    3. no change in water mass in the system $\left(\Delta M_p = 0\right)$;

    4. all water and air flows are stationary, i.e. constant in time $(m_i = const)$;

    5. concentration of the component(s) in the additive water is constant $\left(c_{j,a} = const\right)$;

    6. in water recycling cooling system independent components j do not participate in chemical transformations and phase transitions, i.e. do not fall into sediments and gas phase, the basic equation 20 is simplified to the equation known in the literature:

$$\bar{K}_{dr} = \frac{\bar{c}_c}{\bar{c}_a} = \frac{\bar{m}_a}{\bar{m}_a - \bar{m}_{vap}}. \tag{27}$$

4. Conclusion

Thus, the known equation is the expression of a special case of an ideal system for which the conditions described above are met (conditions 1 to 6). Experience has shown that a system close to perfect can only be replicated in a laboratory setting. Real TPP recycling systems are far from ideal and require a more complex system of equations (models) to describe.

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