Individual task #3
Steam Generators of Nuclear Power Plant

Topic 3. Heat exchange on the side of the working fluid

Saturated steam generator heated by water under pressure with a submerged heat exchange surface. Coolant (non-boiling water) flows inside the heat exchange tubes; boiling water – on the outside. On the side of the working fluid the tube walls are covered with a fouling deposit layer with given thickness. Initial data should be taken according to tasks #1 and #2. Consider the circulation ration into economizer k_c.

The task is:

- to calculate the convective heat transfer coefficients α_{1in} and α_{1out} from the coolant to the tube walls for the inlet and outlet sections of economizer and evaporator;
- to calculate the convective heat transfer coefficients α_{2in} and α_{2out} from the tube walls to the boiling working fluid for the inlet and outlet sections of economizer and evaporator;
- to calculate the overall heat transfer coefficients k_{in}, k_{out} and the mean overall heat transfer coefficient k_{mean} for both economizer and evaporator;
- to calculate the critical heat flux $q_{кр}$ and check the boiling regime;
- determine the length of single heat exchange tube.

Notes:

- the tube wall is assumed to be a plane wall;
- the thermal conductivity of the fouling is λ_{foul} = 2.5 W/(m·K);
- the conductivity of tube material should be determined according to equation X18H10T (λ=[W/(m K)]=0,0182*T+14);
- as the initial approximation of the heat flux density we can take: for the inlet (along the coolant direction) – $q_{in} = 3\cdot 10^5$ W/m^2; for the outlet – $q_{out} = 6\cdot 10^4$ W/m^2;
- to calculate the thermal conductivity of the wall's material λ_{wall} we use the mean wall temperature estimated approximately as the average (arithmetic mean) of the temperatures of the coolant t_1 and the working fluid t_2 in the respective section;
- the critical heat flux should be calculated using the formula

$$q_{кр} = 0,16 \cdot r \cdot \sqrt{\rho''} \cdot \sqrt[4]{\sigma \cdot g \cdot (\rho' - \rho'')},$$

where r is the heat of vaporization, J/kg; σ is the surface tension coefficient, N/m; g is the gravitational acceleration, m/s^2; ρ', ρ'' is the density of water and saturated steam, kg/m^3;

- the convective heat transfer coefficient from the working fluid is calculated using the following formulas:

1 – the Kirillov formula $\alpha_2 = 10,45 \cdot q^{0,7} \big/ \left[3,3 - 0,0113 \cdot (T_{s2} - 373)\right]$;

2 – the Kuzmin formula $\alpha_2 = \begin{cases} 5,728 \cdot p^{0,2} \cdot q^{2/3} \quad при \ 0,1 \le p \le 3 \ \text{МПа} \\ 3,195 \cdot p^{3/4} \cdot q^{2/3} \quad при \ 3 < p \le 20 \ \text{МПа} \end{cases}$;

3 – the TsKTI formula $\alpha_2 = 4,36 \cdot q^{0,7} \cdot \left(p^{0,14} + 1,37 \cdot 10^{-2} \cdot p^2 \right)$,

where p is the working fluid pressure, MPa; T_{s2} is the saturation temperature at working fluid pressure, K; q is the heat influx density, W/m^2.

Table 1. Initial data

parameter	1	2	3	4	5	6	7	8	9	10	11	12	13
δ_{foul}, mm	0.10	0.12	0.14	0.15	0.14	0.20	0.13	0.14	0.12	0.14	0.12	0.14	0.14
k_c	6.0	5.5	5.0	4.5	4.0	3.5	4.0	4.5	5.5	5.0	4.5	4.0	3.5
formula number	1	2	3	1	2	3	1	2	3	1	2	3	1