NPP STEAM GENERATORS

Operating conditions of heating surface with forced working fluid flow

Lecture outline

Thermal maldistribution (tube-to-tube temperature imbalance):

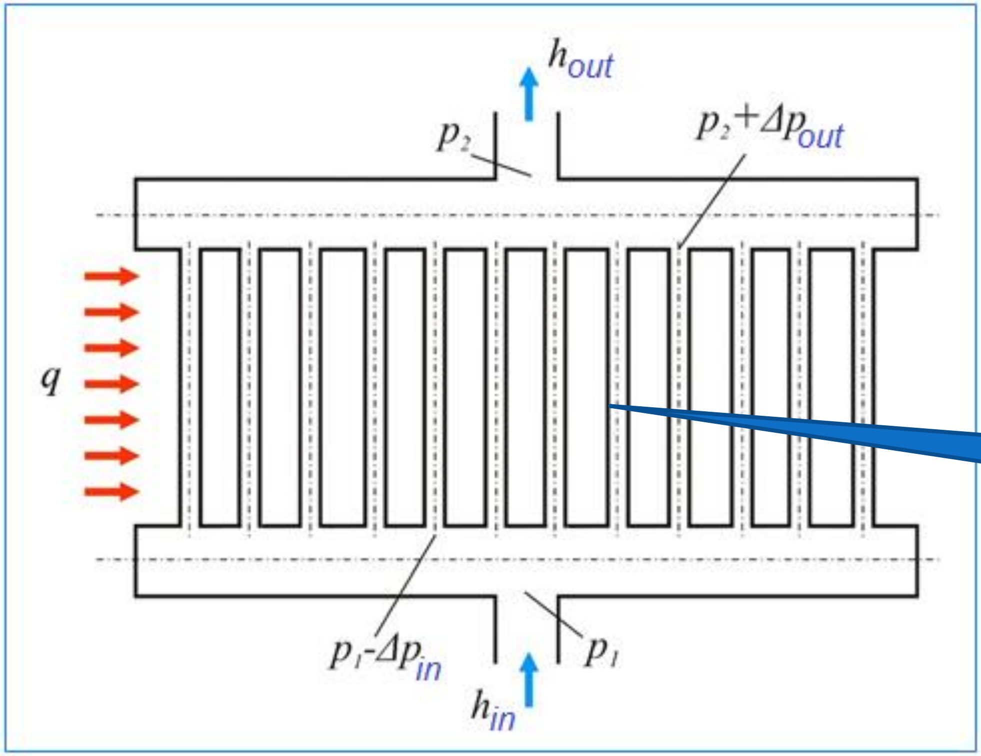
- ✓ thermal and hydraulic non-uniformity;
- ✓ ways to prevent thermal maldistribution;

Adjustment calculation:

- ✓ variation of operational parameters;
- ✓ moderation of steam generator load;
- ✓ reserve coefficient.

Thermal maldistribution

Thermal maldistribution



Heat exchange tubes

Heat transfer surface consists of parallel-channel heated tubes.

Heated water flows in tubes from bottom to top (upstream)

Here h_{in}, h_{out} – water enthalpy at the inlet and outlet of heat transfer surface;
Δp_{in}, Δp_{out} – pressure drops at the inlet and outlet of tubes

Thermal maldistribution

Enthalpy rise for a tube operating under average conditions, J/kg

$$\Delta h_{av} = \frac{q_{av} \cdot S_{av}}{D_{av}}$$

Enthalpy rise for an individual tube, J/kg

$$\Delta h_t = \frac{q_t \cdot S_t}{D_t}$$

Here q – heat flux density, W/m²;
S - heat transfer surface area of an individual tube, m²;
D – flow rate of water passing through an individual tube, kg/s

Thermal maldistribution

It is impossible to ensure constant flow rate of the medium for all tubes. Thus, different variants can be found for individual tubes:

$$\Delta h_t = \Delta h_{av}$$

$$\Delta h_t > \Delta h_{av}$$

$$\Delta h_t < \Delta h_{av}$$

Definition of «thermal maldistribution»

Nonidentity of heat transfer surface tubes with regard to enthalpy rise is called thermal maldistribution η

$$\eta = \frac{\Delta h_t}{\Delta h_{av}}$$

$$\eta = \frac{q_t \cdot S_t}{D_t} \cdot \frac{D_{av}}{q_{av} \cdot S_{av}} = \frac{q_t}{q_{av}} \cdot \left(\frac{D_t}{D_{av}} \right)^{-1} = \eta_T \cdot \eta_H^{-1}$$

The formula above comprises two ratios

$$\eta_T = \frac{q_t}{q_{av}}$$ - *thermal non-uniformity;*

$$\eta_H = \frac{D_t}{D_{av}}$$ - *hydraulic non-uniformity*

There is no thermal maldistribution if:

$$1)\ \eta_T = 1 \quad u \quad \eta_H = 1;$$

$$2)\ \eta_T = \eta_H$$

Problems that occur under thermal maldistribution conditions

If $\Delta h_t > \Delta h_{av}$ in economizers, some tubes operate at medium temperature exceeding the design temperature.

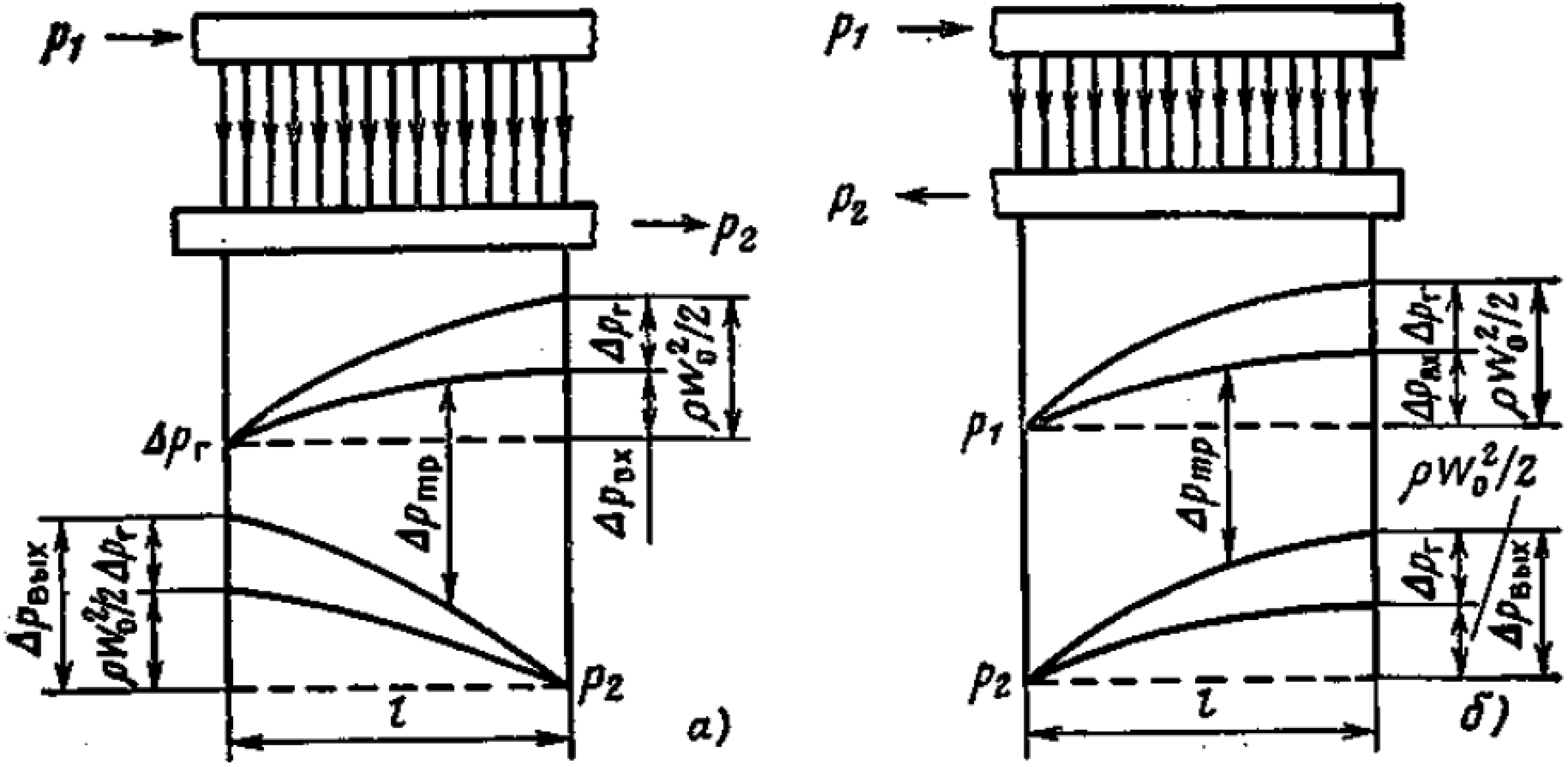
In this case the tube wall temperature may exceed the permissible temperature

$$t_{wall} < t_{wall}^{perm}$$

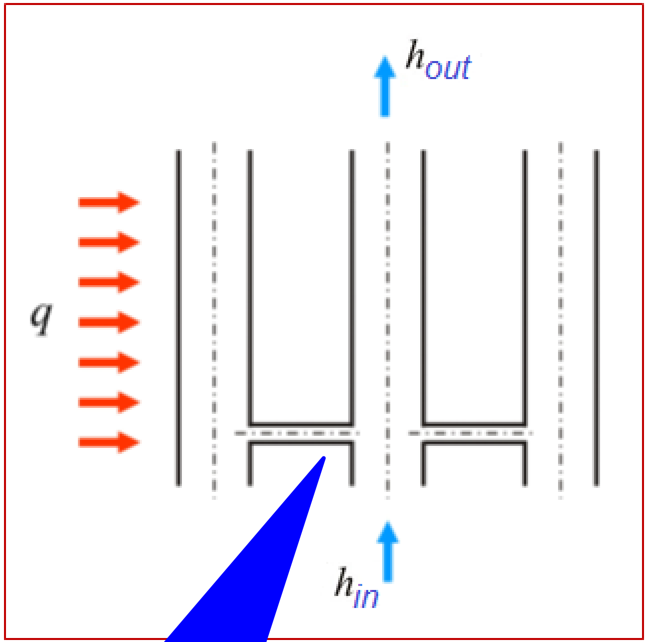
If $\Delta h_t > \Delta h_{av}$ in evaporators, transition of some tubes into the impaired heat transfer mode is possible

$$x_{out} > x_{bnd}$$

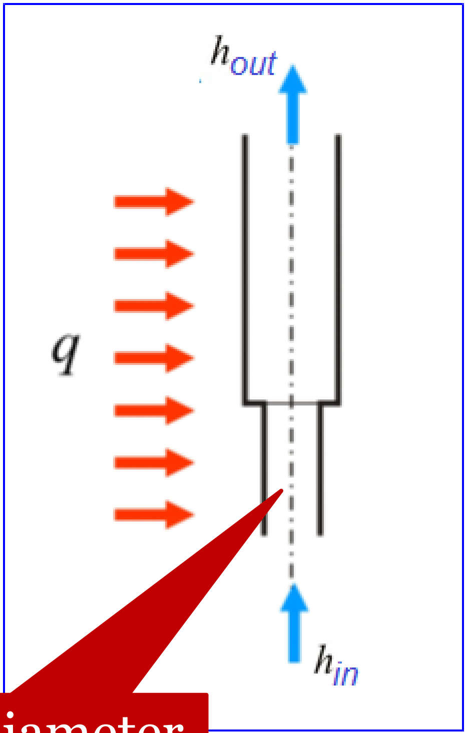
Maldistribution in header



Ways to prevent thermal maldistribution

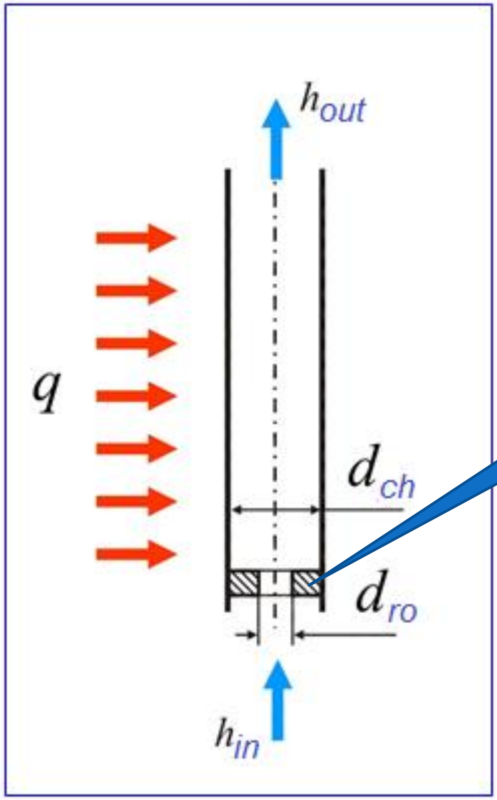


balancing headers



Variable diameter of the tube

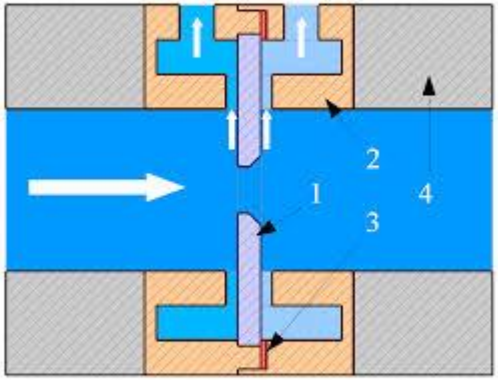
The main method for the prevention of tube-to-tube temperature imbalance is to install orifices on all the tubes



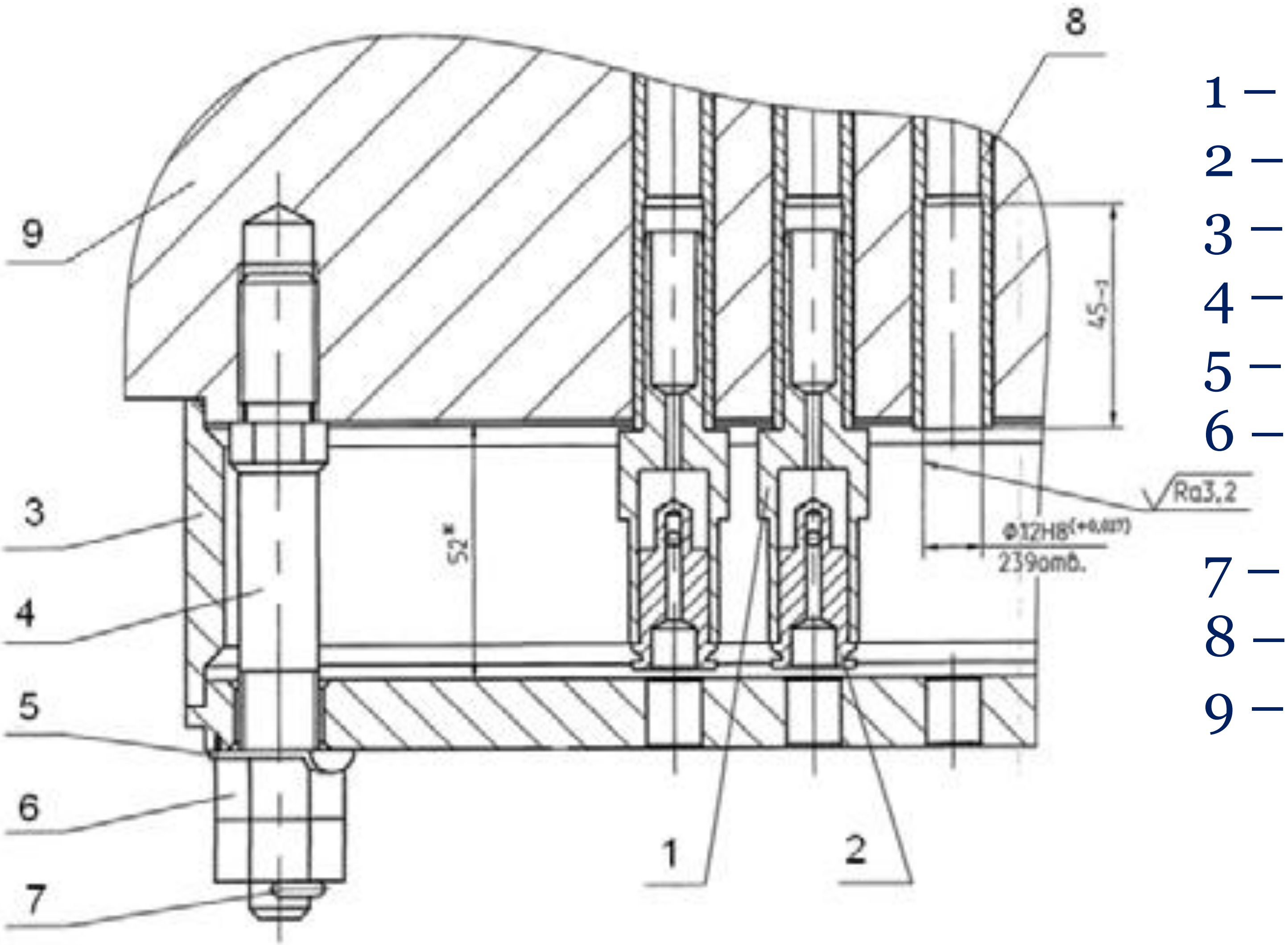
Restricting orifice

Here d_{ch} – channel (tube) diameter;
d_{ro} - orifice diameter

Restricting orifice



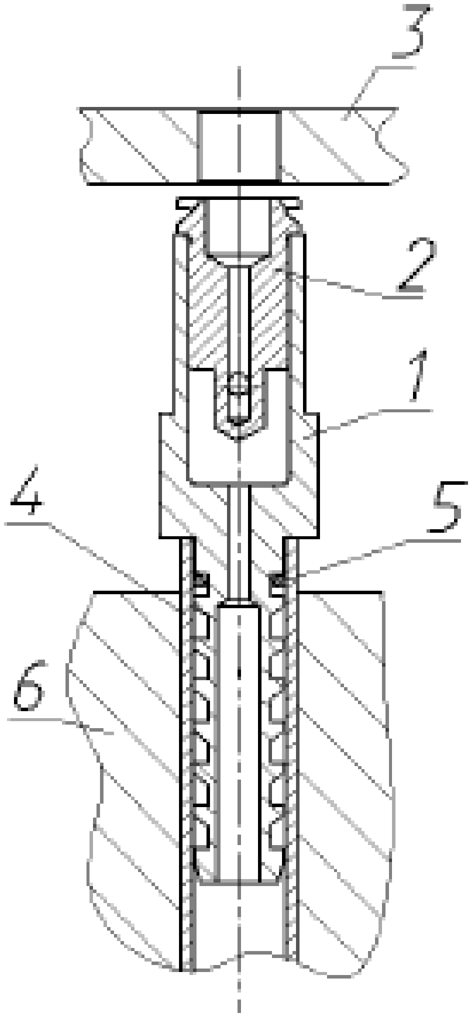
Throttling device

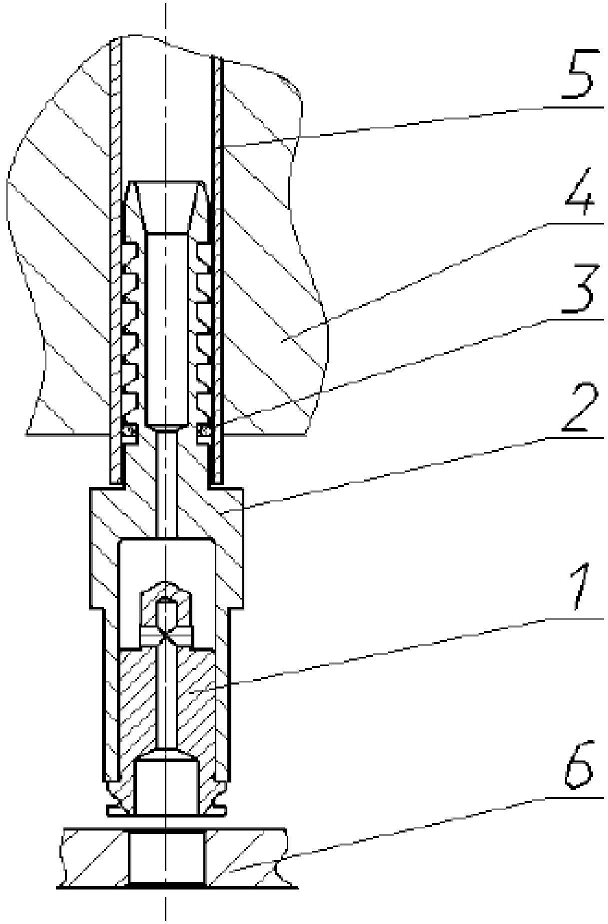


1 – connector
2 – throttle
3 – fixing mesh
4 – hairpin
5 – orifice
6 – screw

7 – wire
8 – tube
9 – tube desk

Throttling device





Adjustment calculation

There are two types of adjustment calculations:

- t_1=var, p_2=const;
- t_1=const, p_2=var.

Algorithm of SG calculation at different load/power

Initial data: Q (MW), p_2 (MPa), F (m^2), G (kg/s)

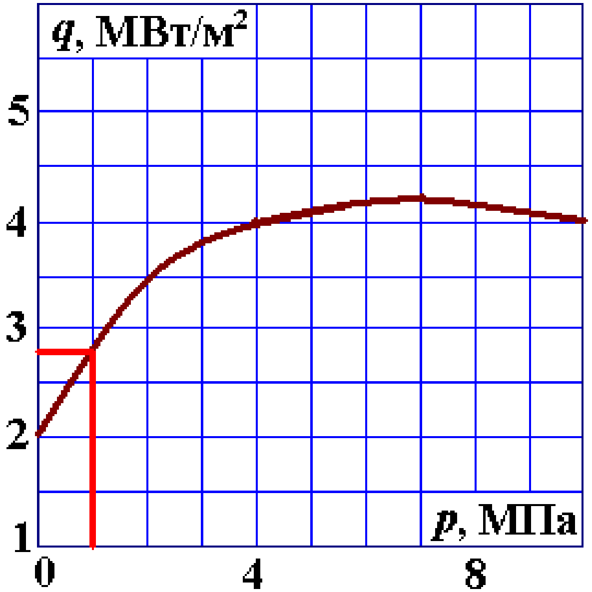
Determined parameters:

1. The inlet coolant temperature is set t_{1in}.
2. The outlet temperature is determined as $t_{1out}=t_{1in}-Q/(G\ c_p)$
3. The calculation is performed according to design calculation procedure and it is repeated until given and obtained heat exchange surface area values have become similar within the reasonable error (usually, 1 %).

Adjustment calculation

Typical cases for adjustment calculation:

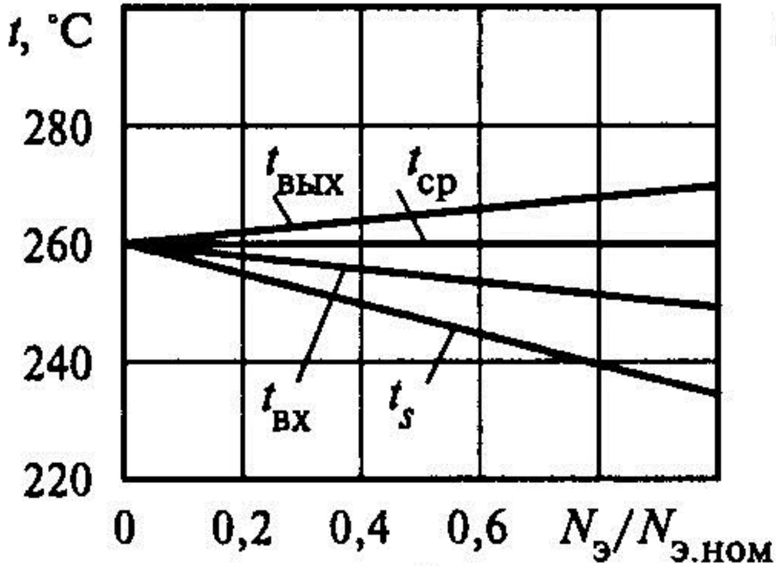
- The decreasing of heat exchange surface area (F=var);
- The increasing in fouling scales thickness (δ=var);
- The decreasing in pressure during emergency, leakage of working fluid (p_2=var);
- The change in load of SG (Q=var, t_1=var or p_2=var);
- The change in coolant flow rate during emergency (G=var).

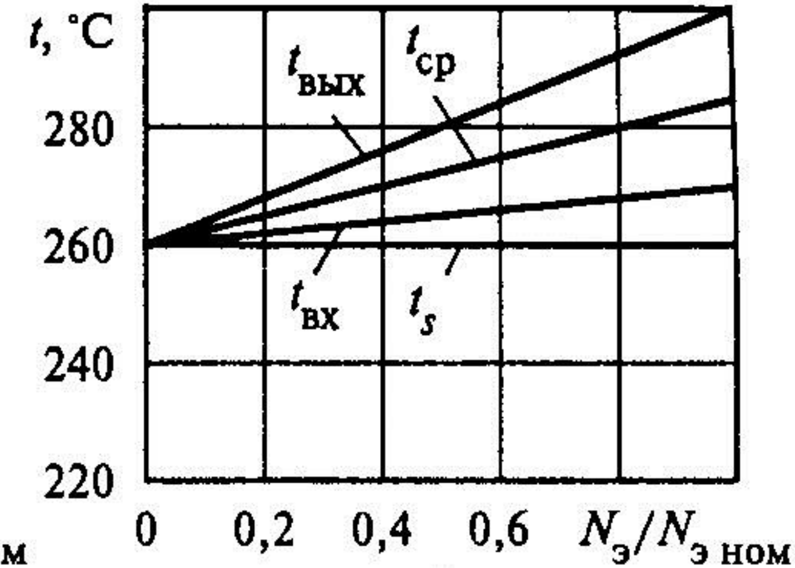


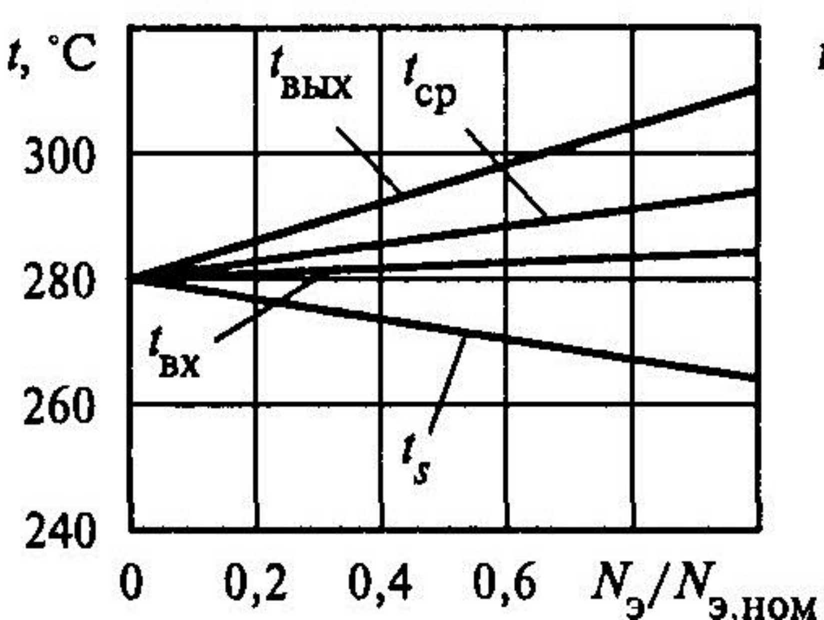
Major parameters:

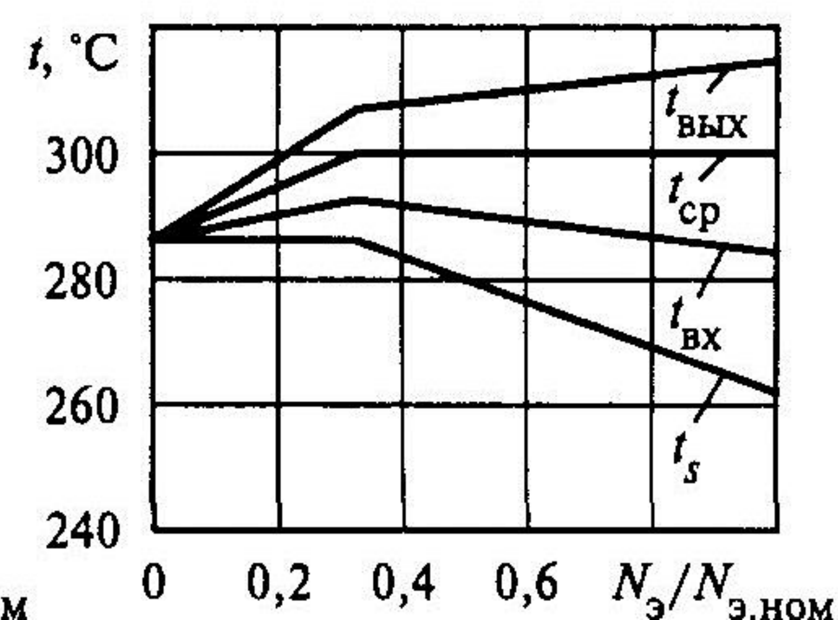
1. Critical heat flux (at p_2=var);
2. Tube wall temperature (at δ=var).

The load variation









Reserve coefficient

Reserve coefficient of SG:

$$\Psi = F_{calc} / F_{real} = \Psi_{sc} \Psi_{ineff} \Psi_{clos}$$

Ψ_{sc} – reserve coefficient due to scale formation, taken as 1,1;
Ψ_{ineff} – reserve coefficient due ineffective flow distribution,
Ψ_{clos} – reserve coefficient due tube closure (1,01 – for BN SG).

Overall Ψ value is taken according to recommendation:

- For SG of VVER unit – 1,15;
- For SG of BN unit – 1,1;
- For high and low pressure heaters – 1,1;
- For other heat exchangers – 1,1;
- For separator-superheater:
  - For 1st stage of multistage devices – 1,0;
  - For other stages of multistage devices or single-stage devices – 1,0.

Thank you for attention