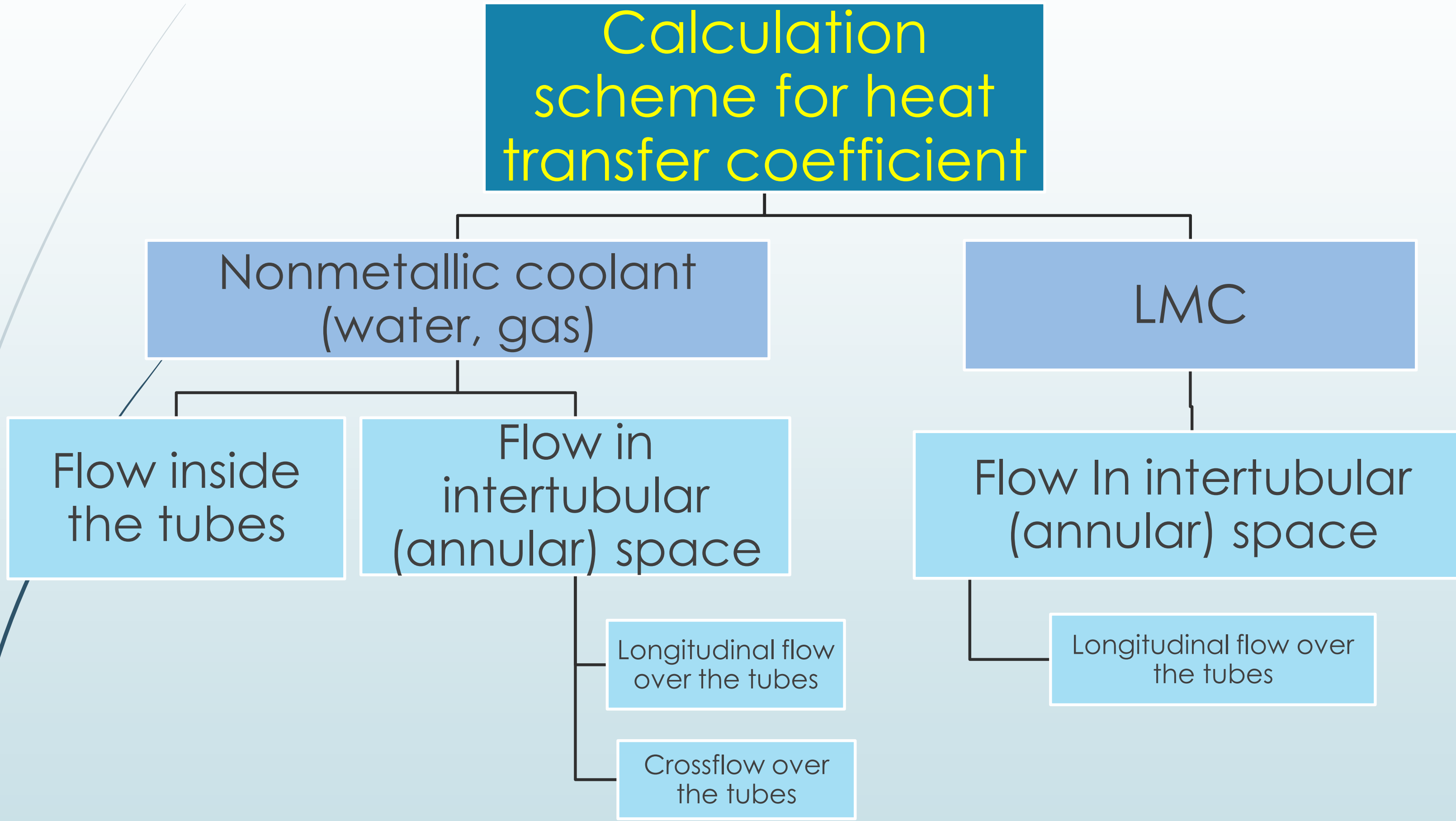
NPP Steam Generators

Heat transfer with single-phase coolants in NPP SGs

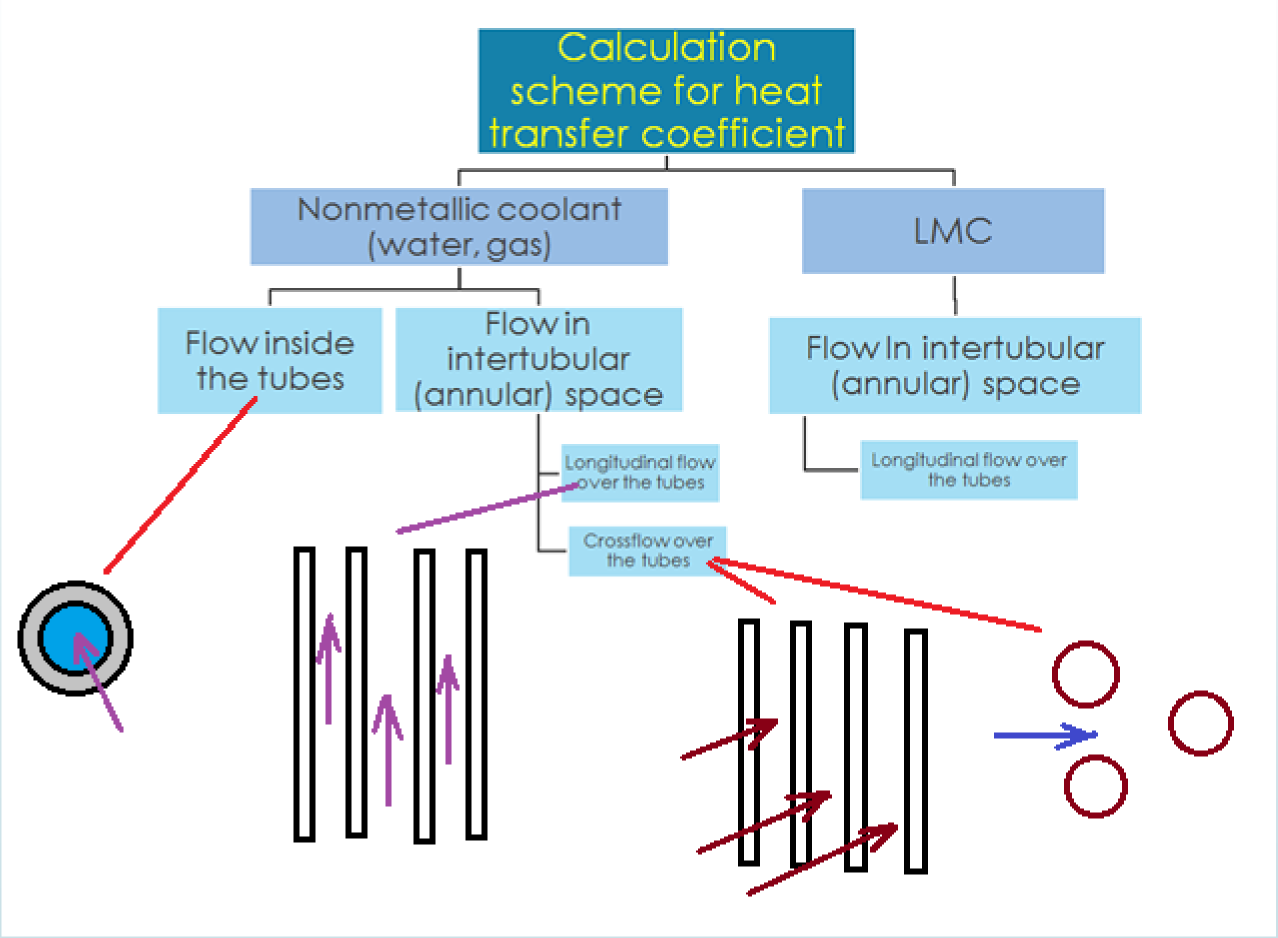
OUTLINE

Heat transfer: nonmetallic coolant flow
Heat transfer: metallic coolant flow

Formula selection algorithm for calculation of heat transfer in single-phase flow



Formula selection algorithm for calculation of heat transfer in single-phase flow



General equation for nonmetallic fluids (circular channel)

Turbulent flow of fluids and gases in the range *Pr* = 0.5 … 200 and *Re* = 10^4 … 10^6

$$Nu_0 = \frac{0,023 \cdot \mathrm{Pr} \cdot \mathrm{Re}^{0,8} \cdot C_t}{1 + 2,14 \cdot \mathrm{Re}^{-0,1} \cdot \left(\mathrm{Pr}^{0,7} - 1\right)}$$

Here *Re* is the Reynolds number; *Pr* is the Prandtl number; C_t is the correction for non-isothermal flow

Correction for non-isothermality C_t

$$C_t = \left(\frac{\Pr_f}{\Pr_{wall}} \right)^n$$

Notes:

а) n=0.11 – at fluid heating;

б) n=0.25 – at fluid cooling;

в) Pr_f, Pr_{wall} – *Prandtl number at mean temperature of the fluid and tube wall, accordingly.*

Calculation algorithm of C_t correction

1. Determine representative temperatures of coolant t_1 and working fluid t_2
2. Identify wall temperature t_{wall} ~ $t_{wall}=(t_1+t_2)/2$
3. Determine thermal physical properties at temperature t_{wall}
4. Calculate correction C_t
5. Calculate heat transfer coefficient on the working fluid side
6. Calculate overall heat transfer coefficient
7. Calculate specific heat flux q
8. Calculate t^{cl}_{wall} (design temperature)
9. Compare t^{cl}_{wall} and t_{wall}

Formulas for superheated steam (circular channel)

Turbulent flow in the range of Prandtl numbers from 0.5 to 200 and Reynolds numbers from 10^4 to 10^6

$$Nu_0 = 0,028 \cdot \mathrm{Re}_{st}^{0,8} \cdot \mathrm{Pr}_{st}^{0,4} \cdot \left(\rho_w / \rho_{st}\right)^n$$

Notes:

а) $n=1.15$ – at coolant heating;

б) $n=2.3$ – at coolant cooling;

в) ρ_{st}, ρ_w – *density of steam at mean temperature of fluid flow and tube wall, correspondingly.*

Formulas for nonmetallic coolants (*longitudinal* flow over tube bundle)

$$Nu = \varepsilon \cdot Nu_0$$

Here Nu_0 – Nusselt number by the formula for circular channel;

ε – correction factor

$$\varepsilon = 1{,}1 \cdot \left(\frac{d_h}{d_{out}} \right)^{0{,}1}$$

Formulas for nonmetallic coolants (crossflow over tube bundle)

$$Nu = C_Z \cdot Nu_1$$

Here Nu_1 is the Nusselt number for a single tube in the centre of a bundle (crossflow);
C_Z – correction factor:

$$C_Z = 1{,}032 - 0{,}559/z + 0{,}2078/z^2$$ - in-line array;

$$C_Z = 1{,}048 - 0{,}712/z + 0{,}2837/z^2$$ - staggered array;

$$Nu_1 = c \cdot \mathrm{Re}^n \cdot \mathrm{Pr}^{0.36}$$

Here *coefficients* c *and* n *depend on Re and the type of tube arrangment in bundle*

Dependence of C_z on z for corridor array

z	1	2	3	4	5	6	7
C_z	0.681	0.804	0.869	0.905	0.929	0.945	0.956

Formulas for metallic coolants (flow in tubes)

This type of heat transfer is the most thoroughly studied. Empirical formulas:

$$Nu = 5 + 0{,}025 \cdot Pe^{0{,}5} \quad npu\ Pe < 4 \cdot 10^{3}$$

For contaminated coolants (emergency mode) the following formula types are recommended:

$$Nu \approx 3 + 0{,}014 \cdot Pe^{0{,}8} \quad npu\ Pe < 4 \cdot 10^{4}$$

Formulas for metallic coolants (longitudinal flow over tube bundle)

$$Nu = 7{,}55 \cdot x - 20 \cdot x^{-13} + 0{,}041 \cdot x^{-2} \cdot Pe^{0{,}56 + 0{,}19 \cdot x}$$

Here *x* is the relative pitch (spacing) of the array (grid):

$x = S_1 / d_{out}$ - triangular, square arrays;

$x = \sqrt{S_1 \cdot S_2} / d_{out}$ - staggered, in-line (corridor) arrays;

Thank you for attention