NPP STEAM GENERATORS

Two-phase flows and their characteristics

Lecture plan

- Classification of two-phase flows
- Characteristics of two-phase flows
- Calculation of pressure drops for two-phase flow

Definition of 'two-phase flow'

Mixture of fluid and steam coexisting in a flow in different forms (bubbles, droplets, etc)

One phase is saturated water, the other phase is dry saturated steam

Classification of two-phase flows

- by character of the mutual phase flow (lifting unidirectional, down unidirectional, counter-current);
- by flow pattern (bubbly, slug, dispersed-annular, dispersed);
- by character of phases' relative disposition (homogeneous model, heterogeneous model);
- by intensity of interaction (equilibrium, quasi-equilibrium, non-equilibrium);
- by time character of the processes (stationary, non-stationary)

Types of two-phase flows depending on flow structure

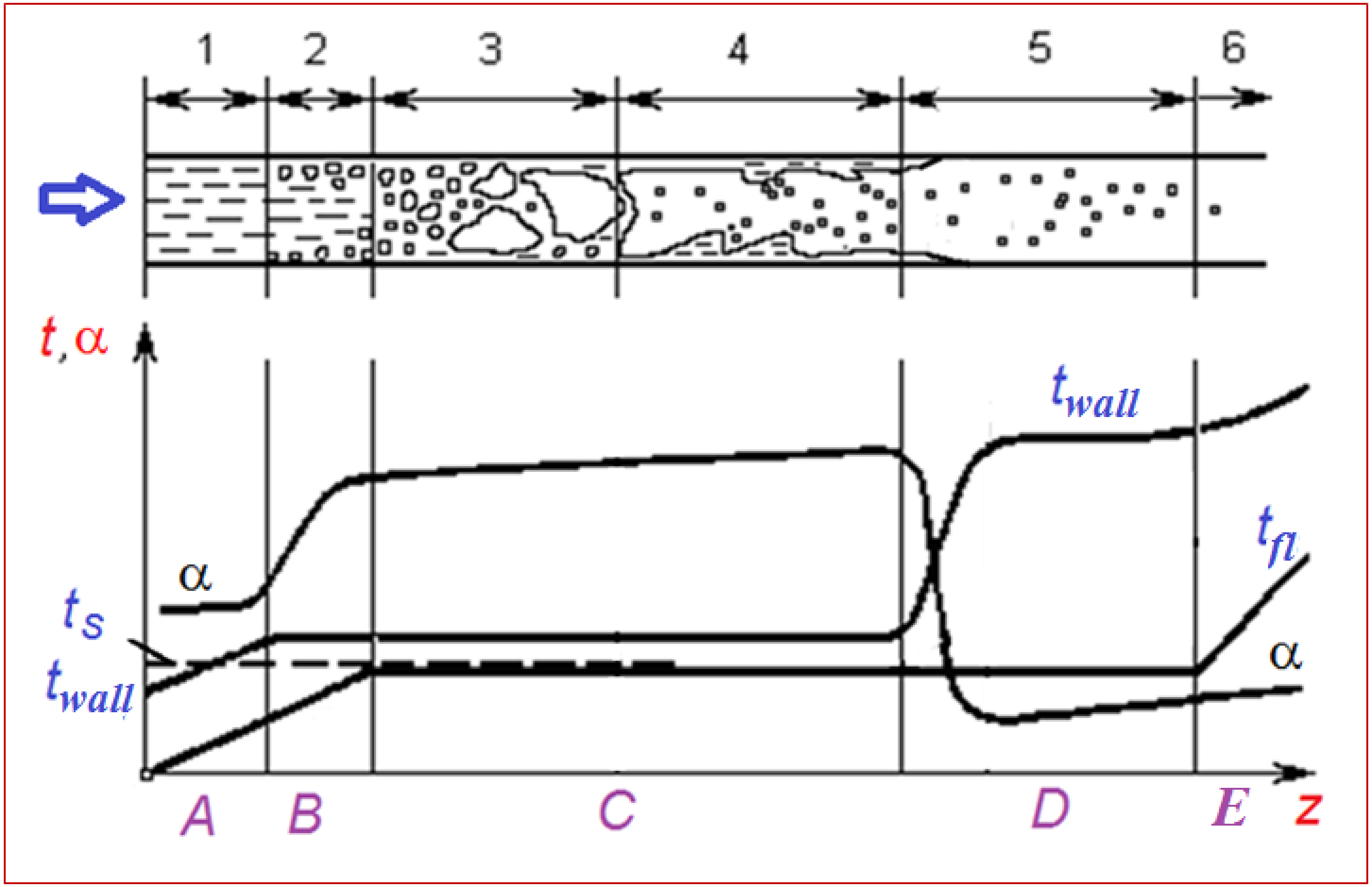
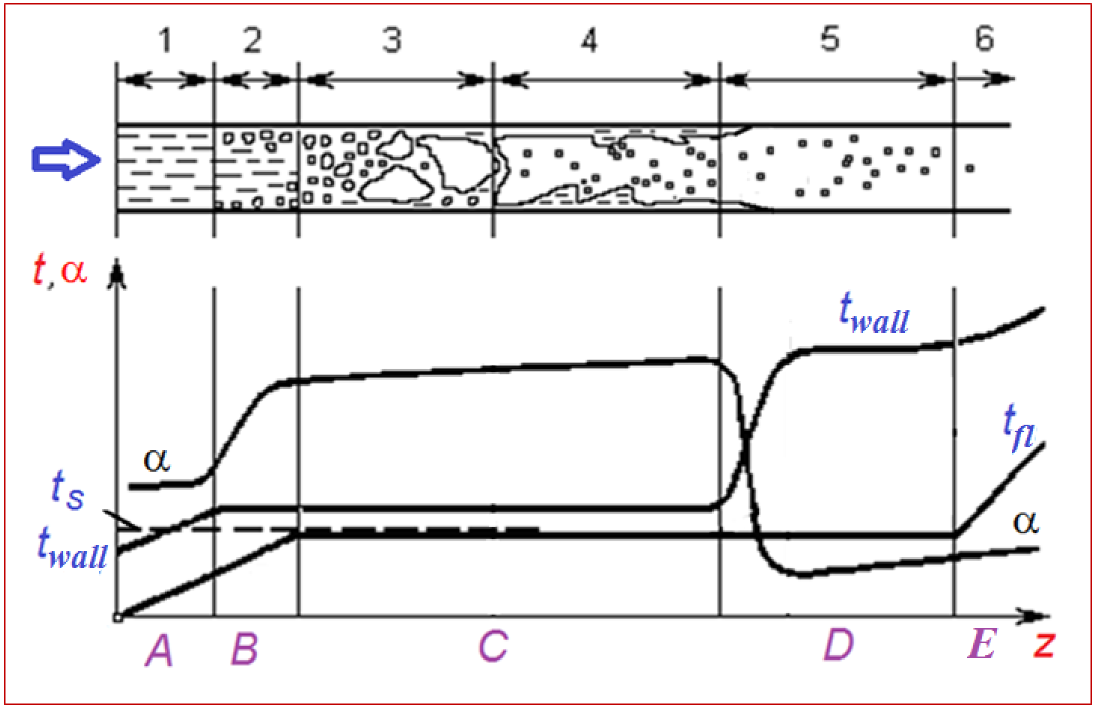


Fig. Change in flow structure along the length of the heated channel

TYPES OF TWO-PHASE FLOWS DEPENDING ON FLOW STRUCTURE



Legend:

t_S – saturated temperature;

t_{wall} – wall temperature (heating surface);

t_{fl} – bulk temperature of the medium (flow);

α – heat transfer coefficient from the wall to the two-phase flow

Characteristics of flow patterns

1- water (single-phase flow);
2 – bubbly (mist) flow (Small bubbles are evenly distributed in water flow.);
3 – slug flow (the flow comprises small bubbles and large ‘slugs’.);
4 – dispersed annular flow (water film is flowing along the channel wall, steam with water droplets – in the centre of the channel.);
5 – dispersed flow (All the water in the form of droplets is distributed in the steam flow.);
6 – superheated steam (single-phase flow)

Two-phase flow characteristics

1. Flow rates
2. Steam quality
3. Velocities
4. Void fractions
5. Integral characteristics of the mixture

1. Flow rates

1.1. Flow rates

$$D_{mix} \text{ or } D = D_{st} + D_w$$

Here:

D_{mix} or D – *mass flow rate of the mixture*

D_{st} – *mass flow rate of steam*

D_w – *mass flow rate of water*

1. Flow rates

1.2. Volumetric flow rates

$$V_w = D_w \cdot \upsilon'$$

$$V_{st} = D_{st} \cdot \upsilon''$$

Here: υ', υ'' - specific volumes of water and steam

2. Steam quality (flow quality)

$$x = \frac{D_{st}}{D}$$

$$x = \frac{h - h'}{h'' - h'} = \frac{h - h'}{r}$$

Here: h – enthalpy of the mixture;
h', h'' - enthalpy of saturated water and steam

2. STEAM QUALITY

Heat balance for any section of the evaporation zone

$$D \cdot h = D_{st} \cdot h'' + \left(D - D_{st}\right) \cdot h'$$

$$\frac{D}{D} \cdot h = \frac{D_{st}}{D} \cdot h'' + \frac{D - D_{st}}{D} \cdot h'$$

$$h = x \cdot h'' + \left(1 - x\right) \cdot h'$$

$$x = \frac{h - h'}{h'' - h'}$$

Note. *Another name for x* *relative enthalpy*

3. Velocities

3.1. Circulation rate (circuit velocity)

$$w_0 = \frac{D \cdot \upsilon'}{f_{ch}} = \frac{D}{f_{ch} \cdot \rho'}$$

3.2. Mass velocity

$$\rho' \cdot w_0 = \rho_1 \cdot w_1 = \rho_{mix} \cdot w_{mix} = \ldots = \rho\, w = \frac{D}{f_{ch}} = const$$

Here: ρ_{mix}, w_{mix} – density and velocity of the mixture;
f_{ch} – area of the channel’s flow passage

EXAMPLE

Loss of pressure due to friction during a two-phase mixture

$$\Delta p_{fr} = \left[1 + \overline{\psi x}\left(\frac{\rho'}{\rho''} - 1\right)\right]\zeta_0 \frac{w_0^2 \rho'}{2}\frac{l}{d}$$

circuit velocity

3. Velocities

3.3. Superficial flow velocities of the phases

$$\omega_0' = \frac{D_w \cdot \upsilon'}{f_{ch}}$$

$$\omega_0'' = \frac{D_{st} \cdot \upsilon''}{f_{ch}}$$

Here: υ', υ'' - specific volumes of water and steam

Expression of Circulation rate w_0 through superficial velocities of phases

$$D = D_{st} + D_w = \ldots$$

$$D = f_{ch} \cdot \frac{w_0}{\upsilon'} \qquad D_{st} = f_{ch} \cdot \frac{w_0''}{\upsilon''} \qquad D_w = f_{ch} \cdot \frac{w_0'}{\upsilon'}$$

$$\boxed{w_0 = w_0' + \frac{\upsilon'}{\upsilon''} \cdot w_0''}$$

3.4. Actual phase velocities

$$w' \text{ or } w_w = \frac{D_w \cdot \upsilon'}{f_w} = \frac{w'_0 \cdot f_{ch}}{f_w}$$

$$w'' \text{ or } w_{st} = \frac{D_{st} \cdot \upsilon''}{f_{st}} = \frac{w''_0 \cdot f_{ch}}{f_{st}}$$

Here: f_w, f_{st} – areas occupied by water and steam in cross-section of the channel

4. Slip coefficient

$$R = \frac{w_{st}}{w_w}$$

If the lifting motion of two-phase flow, then

$$R > 1 \quad or \quad R < 1$$

If the two-phase flow is lowering then

$$R > 1 \quad or \quad R < 1$$

FORMULAS FOR SLIP COEFFICIENT CALCULATION

$$R = 1 + 2,54 \cdot d_h^{0,25} \cdot \frac{(1-\pi)}{\upsilon' \cdot (\rho w)}$$

$$R = \left[1 + \left(0,6 + 1,5 \cdot \beta^2\right) \cdot (1-\pi) \cdot Fr^{-0,25}\right]$$

Here: $$\pi = \frac{p}{p_{cr}};$$

$$Fr = \frac{w_0^2}{g \cdot d_h};$$

$$p_{cr} = 221,3 \cdot 10^5 \ Pa$$

5. Void fractions

$$\varphi = \frac{f_{st}}{f_{ch}} = \frac{f_{st}}{f_{st} + f_w} = \frac{1}{1 + \frac{f_w}{f_{st}}}$$

Actual volumetric void fraction

$$w_w = \frac{D_w \cdot \upsilon'}{f_w}$$

$$w_{st} = \frac{D_{st} \cdot \upsilon''}{f_{st}}$$

$$\varphi = \frac{1}{1 + \frac{f_w}{f_{st}}} = \ldots = \frac{x}{x + R \cdot \frac{\upsilon'}{\upsilon''} \cdot (1 - x)} = \frac{1}{1 + R \cdot \frac{\upsilon'}{\upsilon''} \cdot \frac{1 - x}{x}}$$

5. Void fractions

$$\beta = \frac{V_{st}}{V_{st} + V_w}$$

volumetric void fraction

$$V_w = D_w \cdot \upsilon'$$

$$V_{st} = D_{st} \cdot \upsilon''$$

$$\beta = \frac{x}{x + \frac{\upsilon'}{\upsilon''} \cdot (1 - x)} = \frac{1}{1 + \frac{\upsilon'}{\upsilon''} \cdot \frac{1 - x}{x}}$$

5. Integral characteristics of mixture

5.1. Mixture density

actual

$$\rho_{mix} = \varphi \cdot \rho'' + (1 - \varphi) \cdot \rho'$$

$$\rho_{mix} = \rho' - \varphi \cdot (\rho' - \rho'')$$

height-averaged

$$\overline{\rho}_{mix} = \rho' - \overline{\varphi} \cdot (\rho' - \rho'')$$

5. Integral characteristics of mixture

5.2. Mixture velocity

$$\omega_{mix} = \omega_0 \cdot \frac{\rho'}{\rho_{mix}}$$

$$\omega_{mix} = \frac{\omega_0}{1 - \varphi \cdot \left(1 - \frac{\rho''}{\rho'}\right)}$$

Calculation of actual volumetric steam quality φ

Volumetric void fraction is determined by the equation

$$\beta = \left[1 + \frac{\rho''}{\rho'} \cdot \frac{(1 - x)}{x} \right]^{-1}$$

Slip coefficients are calculated by

$$R = \left[1 + \left(0,6 + 1,5 \cdot \beta^{2} \right) \cdot (1 - \pi) \cdot Fr^{-0,25} \right]$$

Actual volumetric void fraction is given as

$$\varphi = \left[1 + R \cdot \frac{\rho''}{\rho'} \cdot \frac{(1 - x)}{x} \right]^{-1}$$

Thank you for attention