NPP STEAM GENERATORS

Boiling crisis

Lecture outline

1. Definition of boiling crisis.
2. Mechanism of boiling crisis.
3. Types of boiling crises.

Boiling crisis

Boiling crisis is the phenomenon of a drastic reduction of heat transfer on the heat exchange surface leading to a sharp increase in its temperature.

Max heat flux that is revealed just before the boiling crisis is called the critical heat flux and is indicated as $q_{crit.}$

Boiling crisis mechanism

The crisis has been studied since the mid previous century.

Main conclusion is that boiling crisis is related to flow regime in the channel.

Main flow regimes

1 – water (single-phase flow);
2 – bubbly;
3 – slug-bubbly;
4 – dispersed-annular;
5 – dispersed;
6 – superheated steam (single-phase flow)

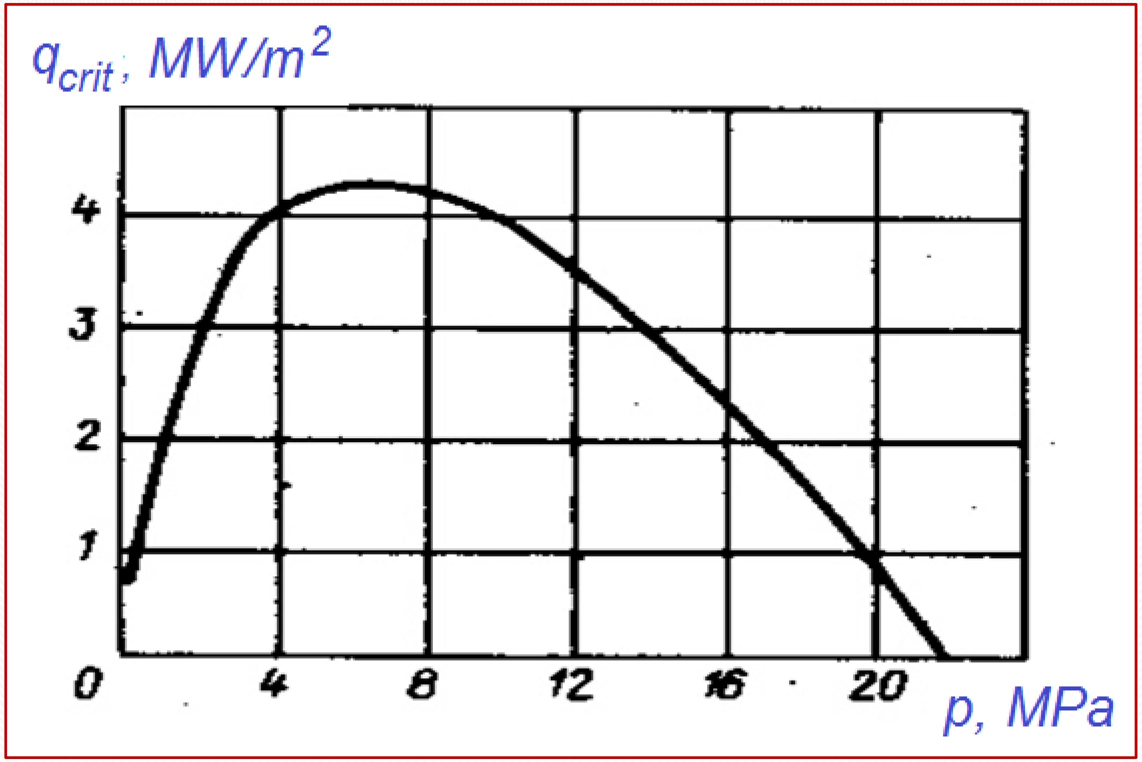
Post-CHF regimes:

- film(steam is at the wall surface, water is in flow core);
- dispersed (steam flows over the wall, water droplets are in flow core)

Types of boiling crisis

- Boiling crisis in pool boiling
- Boiling crisis with forced flow

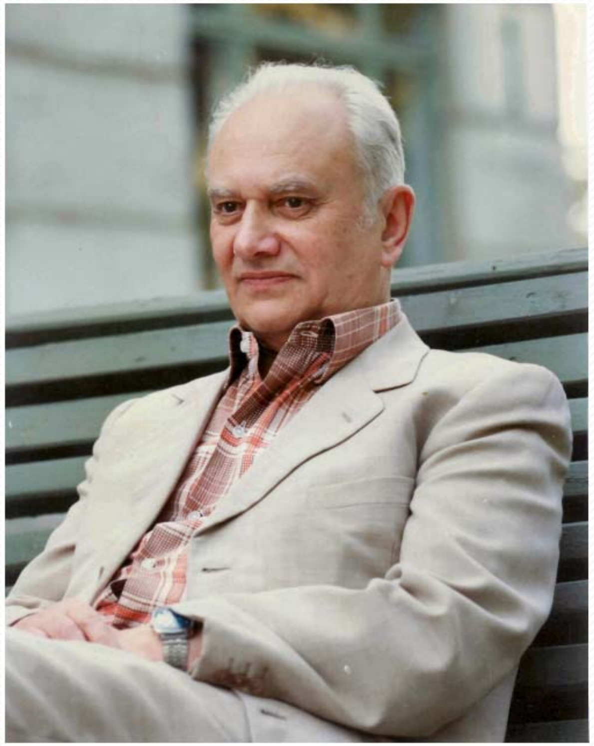
Boiling crisis in pool boiling



Kutateladze formula

$$q_{crit} = 0{,}14 \cdot r \cdot \sqrt{g \cdot \rho''} \cdot \sqrt[4]{\sigma \cdot (\rho' - \rho'')}$$

Kutateladze C.C.



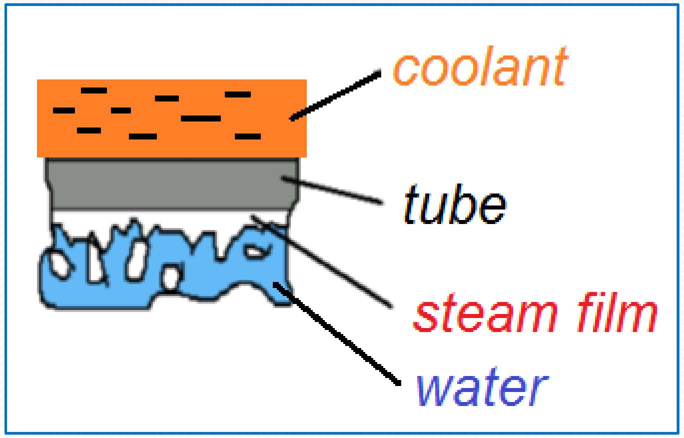
31.07.1914 -21.03.1986

Boiling crisis in channels (in tubes and intertubular space) with forced flow

Boling crisis of the first kind

The impaired heat transfer mode in which a steam film is formed on the tube surface (i.e. upon the transition from nucleate boiling to film boiling) is called the *boiling crisis of the first kind (aka 'departure from nucleate boiling')*.

Critical heat flux (CHF) is the characteristic value for this crisis.



Factors that determine q_{crit}

- x – steam quality (relative enthalpy);
- $\rho\omega$ - mass velocity;
- p – pressure;
- shape and dimensions of heat transfer surface.

Boiling crisis calculation methods

1. By means of analytical equations
2. Table-based methods

Analytical calculation methods for boiling crisis of the 1st kind (departure from nucleate boiling)

Circular tubes

$$q_{crit} = q_{crit8} \cdot \left(\frac{d}{0,008} \right)^{-0,33} \qquad \pm 15\%$$

Here q_{crit} – in MW/m²; p – in MPa

$$q_{crit8} = \left[10,3 - 0,796 \cdot p + 0,0167 \cdot p^2 \right] \cdot \left(\rho w \cdot 10^{-3} \right)^m \cdot exp\left(-1,5 \cdot x \right)$$

$$m = 1,2 \cdot \left[0,25 \cdot \left(0,1 \cdot p - 1 \right) - x \right]$$

Analytical calculation methods for departure from nucleate boiling (*critical heat flux*)

Banks of tubes (plain rods)

$$q_{crit} = 0,65 \cdot (\rho\omega)^{0,2} \cdot (1 - x)^{1,2} \cdot \left(1,3 - 4,36 \cdot 10^{-2} \cdot p\right) \pm 20\%$$

Calculation methods for departure from nucleate boiling

All the utilized formulas are empirical.

Most equations are obtained for uniformly heated rods.

Boiling crisis of the 2nd kind

The impaired heat transfer mode due to the destruction of fluid film upon the transition from a dispersed-annular flow regime to a dispersed flow regime is called the *boiling crisis of the 2nd kind.*

Boundary steam quality x_b is the characteristic value for this crisis.

Boiling crisis of the 2nd kind

Boundary steam quality is not dependent on heat flux density and is defined by the parameters of the two-phase flow. Thus, crisis of the 2nd kind may occur even with *small heat flux*.

Ways to prevent the crisis of the 2nd kind:

- to increase the subcooling up to saturation temperature at channel entry;
- to increase pressure;
- to decrease mass velocity

Analytical identification of boundary (bnd) steam quality

$$x_{bsq} = 1 - 0,86 \cdot \exp\left(-\frac{19}{We}\right)$$

$$We = \frac{(\rho\omega)^2 \cdot d_h}{\rho' \cdot \sigma}$$

Here x_{bsq} – mass steam quality in the beginning of the heat transfer impairment region (boundary mass steam quality)

Look-up table calculation methods for boiling crisis (method of the Institute of Physics and Power Engineering)

General equation

$$q_{crut} = q_m \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4$$

q_m – critical heat flux for a tube bundle (d_h=9.36 mm; L/d_h>300; S/d =1.4);
k_1 – correction for heat diameter value;
k_2 – correction for relative spacing;
k_3 – correction for the effect of entry conditions (for L/d_h);
k_4 – correction for the effect of spacing grid

Look-up table calculation methods for boiling crisis (method of the Institute of Physics and Power Engineering)

The method characterizes data with the mean squared error of 17%.

Total 5240 experimental points obtained on 47 experimental models.

Example of CHF table for tube bundle

P, кПа	ρw, кг/м²с	X= -0,5	X= -0,4	X = -0,3	X= -0,2	X = -0,1	X= 0,0	X= 0,1	X= 0,2	X= 0,3	X= 0,4	X= 0,5	X= 0,6	X= 0,7	X= 0,8	X= 0,9	X= 1,0
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100	25	-	-	-	370	140	72	70	70	68	67	67	53	49	46	43	42
100	50	-	-	-	596	227	118	114	113	111	110	109	89	68	68	68	68
100	100	-	-	-	661	304	189	196	205	215	221	214	174	134	132	132	132
100	200	-	-	-	937	519	324	334	343	342	323	299	243	200	185	189	
100	300	-	-	-	1418	910	573	587	590	569	504	450	365	321			
100	500	-	-	-	1930	1386	859	911	898	884	846	716	479				
100	750	-	-	-	2188	1601	1038	1084	1061	981	977						
100	1000	-	-	-	2416	1795	1210	1249	1213	1061							
100	1500	-	-	-	2813	2093	1462	1472	1418	1358							
100	2000	-	-	-	3181	2377	1689	1689	1588								
100	3000	-	-	-	3951	2981	2196	2163									
100	4000	-	-	-	4963	3687	2799										
100	5000	-	-	-	6307	4481	3525										

Here $q_m = f(x, p, \rho w)$

Thank you for attention