NPP STEAM GENERATORS

Steam separation in NPP SGs

Lecture outline

1. Necessity of separation
2. Steam purity requirements
3. Definition of ‘separation’
4. Design of separation chamber
5. Separation techniques

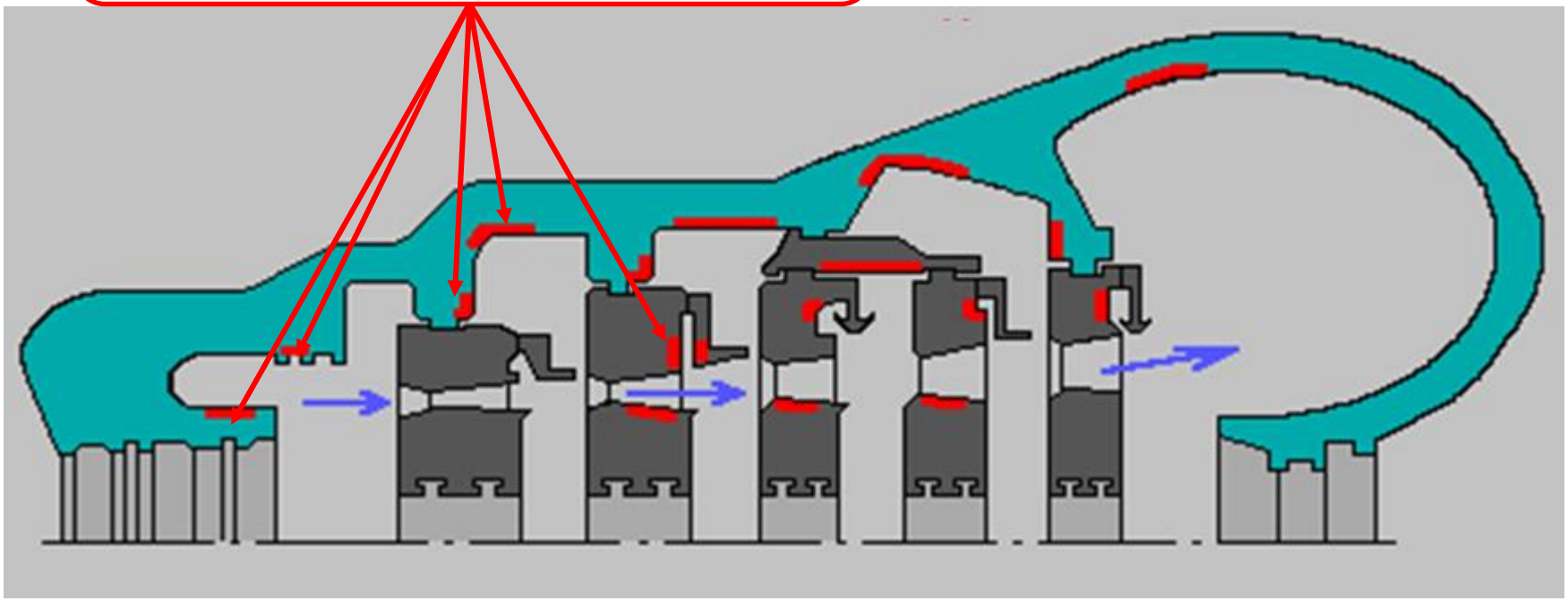
Necessity of separation

Moisture (water droplets) in steam, which is generated in SG's evaporator, contributes to:

- erosive-corrosive wear of steam inlet components of a turbine;
- coverage of turbine blades, pipelines with saturated steam salts (roughness growth, reduced efficiency);
- fouling deposits on the surface of SG superheater tubes (reduced efficiency of heat exchange in superheater)

Necessity of separation

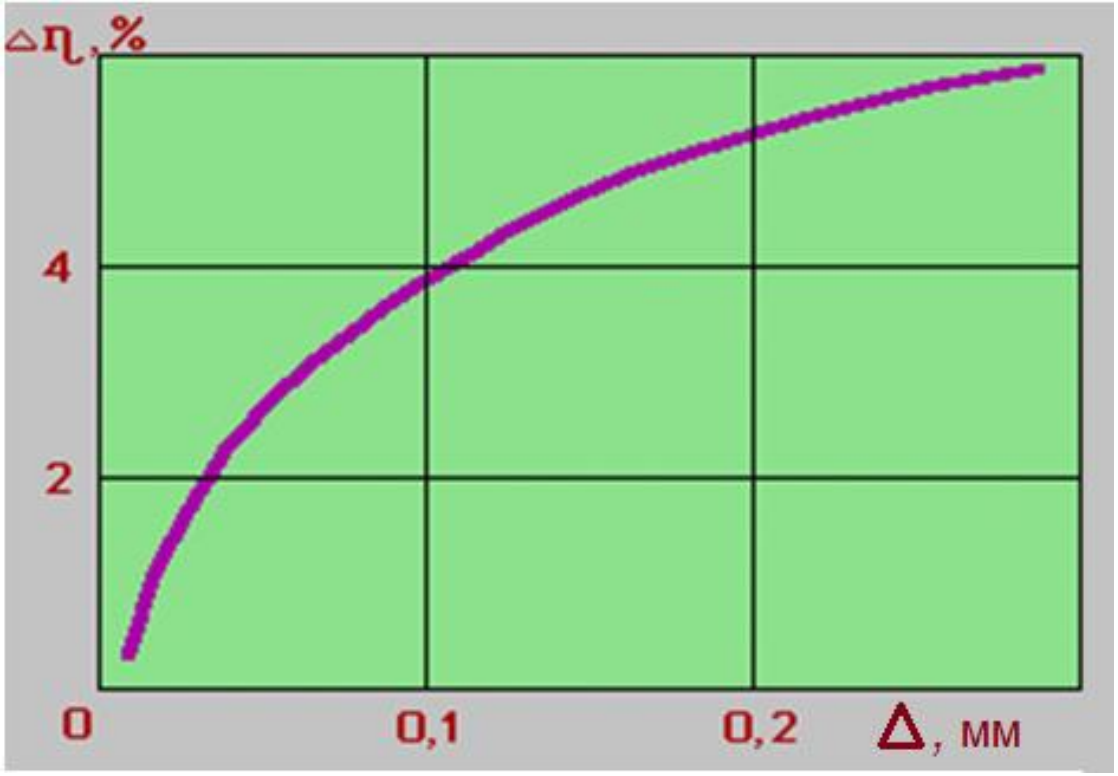
Typical location of erosive-corrosive wear of metal of high pressure cylinder in saturated steam turbines



Characteristic erosive damage of steam turbine blades

Characteristic deposits on steam turbine blades

Necessity of separation



Decrease in efficiency factor of turbine stage with roughness growth

Necessity of separation

VVER (PWR) units employ a steam-turbine cycle with saturated steam of a relatively low pressure (less than 7 MPa).

At such parameters, saturated steam is contaminated only due to the presence of water droplets with dissolved salts and insoluble impurities (solubility of salts in pure steam is almost zero).

At high pressure (exceeding 7 MPa) the content of some substances (iron oxide and silicic acid) in steam rises significantly; a substantial amount of these substances is carried over from heating surfaces with steam.

Salt content of saturated steam

Main objective of quality assurance of saturated steam at low and medium pressure is the restriction of carryover of substances that are present in evaporating water.

In general case the salt content of saturated steam is

$$S_s = \left(y + K_{df} \right) S_w$$

Here S_S, S_W – concentration of impurities in steam and water of SG, mg/kg;

y – moisture content of steam;

K_{df} - distribution factor that characterizes solubility of solids in steam

Necessity of separation

At steam pressure of 5...7,0 MPa, which is typical of modern NPP, solubility of salts in steam is insignificant and can be neglected, i.e. $K_{df}=0$.

Consequently, the total salt content in steam depends only on steam moisture content

$$S_s = y \cdot S_w$$

Thus, to obtain high-purity steam it is necessary to:

- *restrict moisture carryover by steam* y*;*
- *reduce the salt content of impurities in carried moisture* S_w

Steam purity requirements

(*with regard to moisture content*)

- moisture content of steam at saturated steam turbine entry

$y \leq 0{,}2 \ldots 0{,}25$ % ;

- moisture content of steam at superheater entry of a once-through SG $y \leq 0{,}02 \ldots 0{,}05$ %

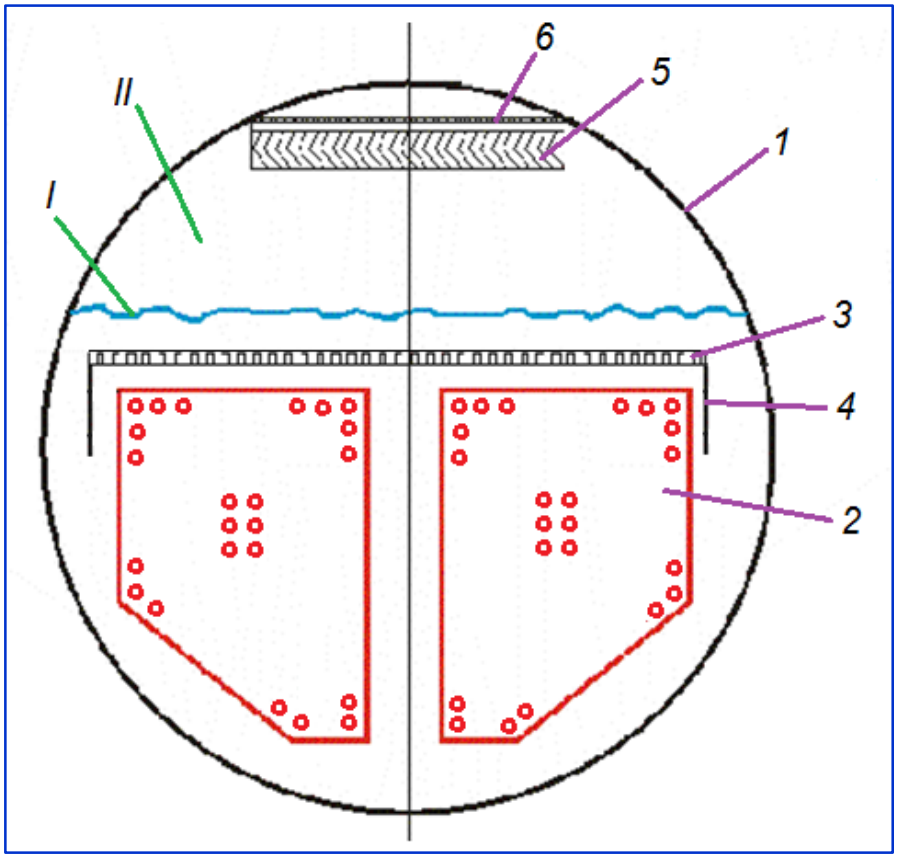
Conclusion:

- **in the steam generators of VVER impurities fall to the turbine with water droplets;**
- **in steam generators BN impurities enter the turbine with superheated steam**

Definition of ‘separation’

Separation of steam is a combination of two processes – separation of steam-water mixture and steam drying.

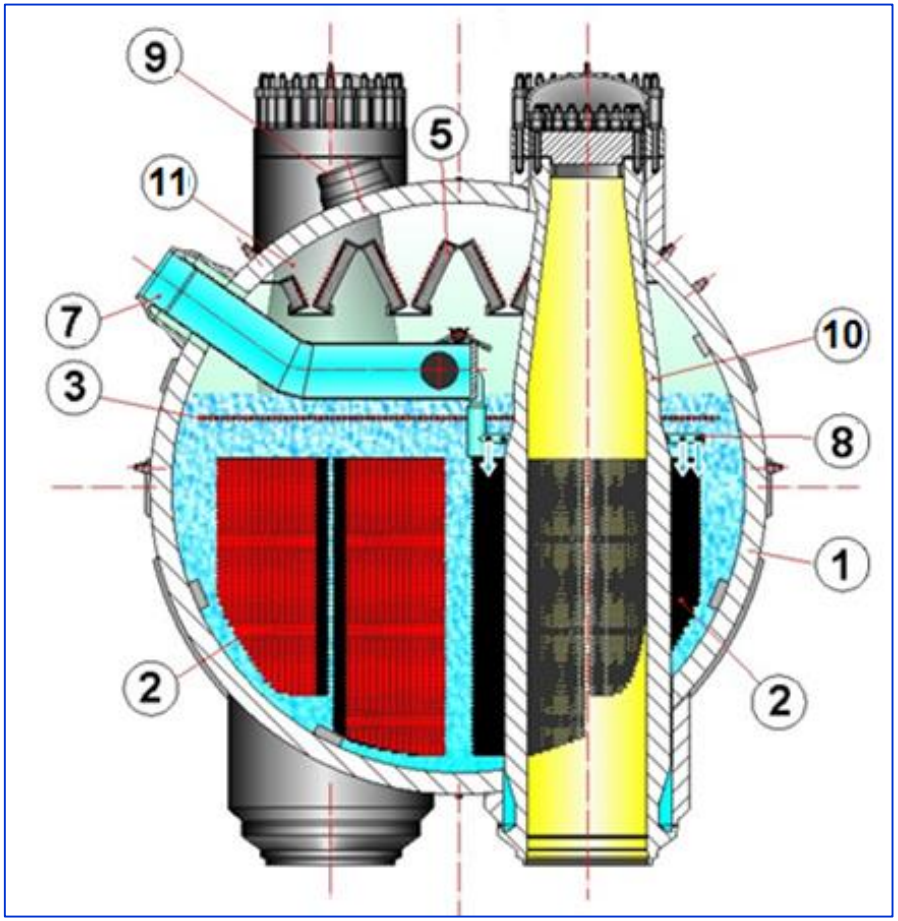
Separation design of horizontal U-tubed SG (WWER)



1 - vessel;
2 – heat-exchange tubes;
3 – submerged perforated plate;
4 – flanges of submerged perforated plate;
5 – louvre separator;
6 – steam-receiving perforated plate;

I – evaporation surface;
II – steam region

Cross section of horizontal U-tubes SG (WWER)

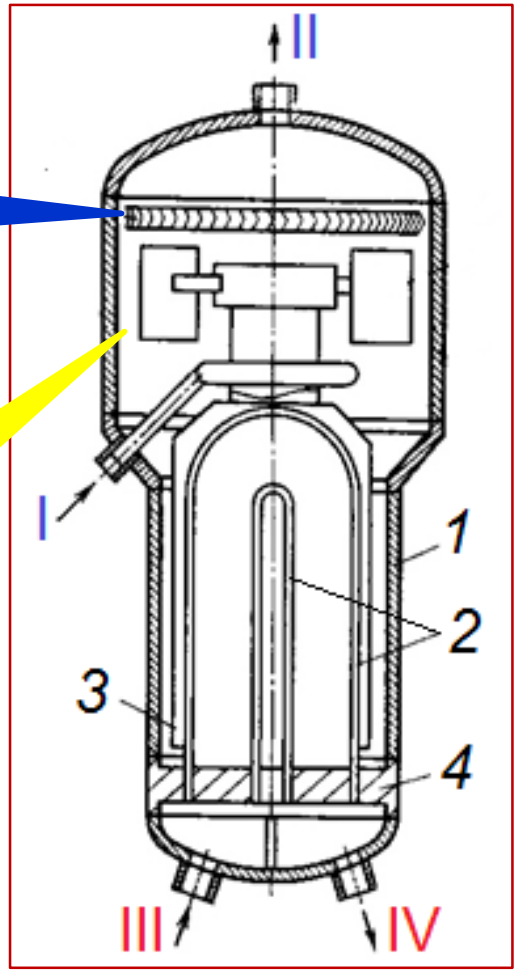


3 – submerged perforated plate;
7 – feedwater supply nozzle;
8 – feedwater distribution system;
9 – steam outlet nozzle;
10, 11 – hot and cold coolant collectors (headers);

Separation design of vertical SG (PWR)

louvre separator

centrifugal separator



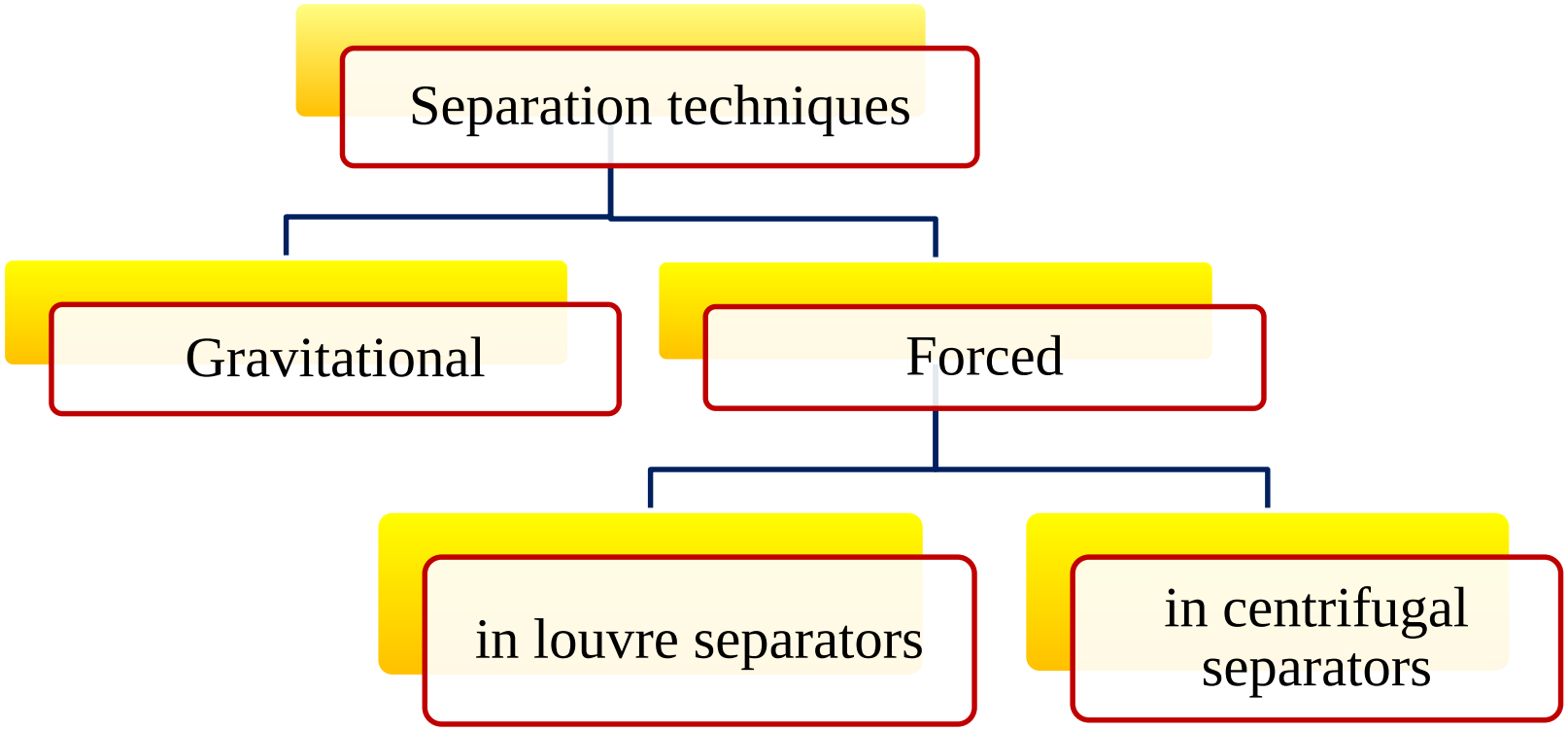
1 - vessel;
2 – heat-exchange tubes;
3 – partitive shell;
4 – tubesheet;

I, II – feedwater inlet, steam outlet;
III, IV – coolant inlet and outlet

Main components of separation drum

- Submerged perforated plate
- Separator
- Steam-receiving perforated plate

Separation techniques in NPP SG



Gravitational separation

Moisture drops are separated by gravitational force.

Gravitational separation

Main factors that determine the efficiency of gravitational separation:

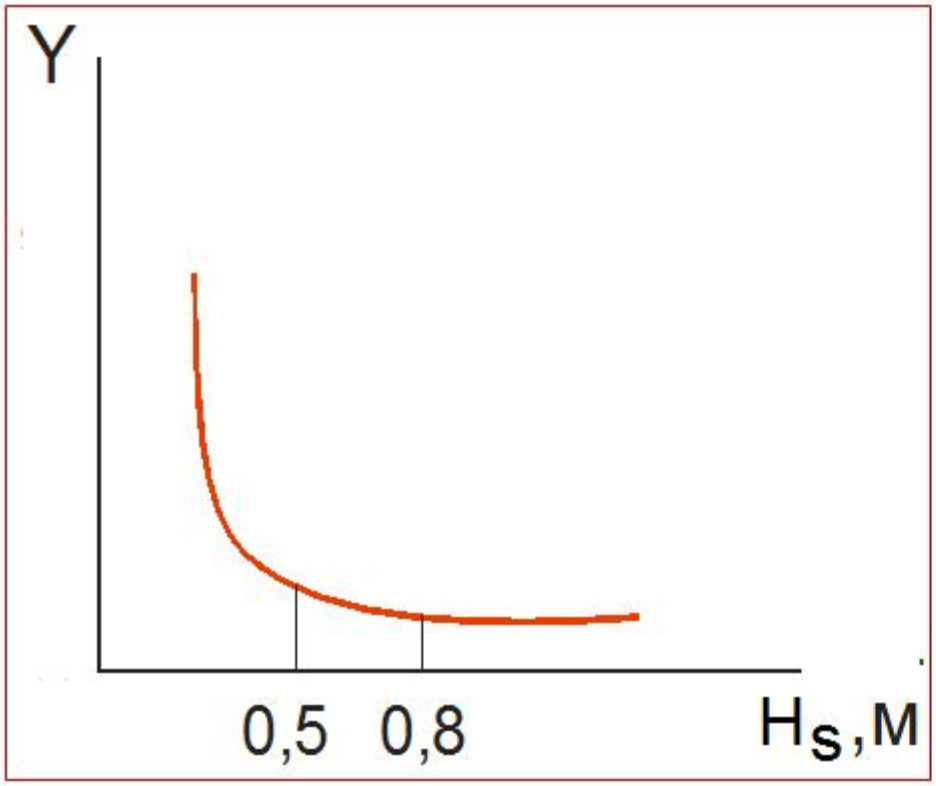
- superficial steam velocity w''_0;
- height of steam region H_S.

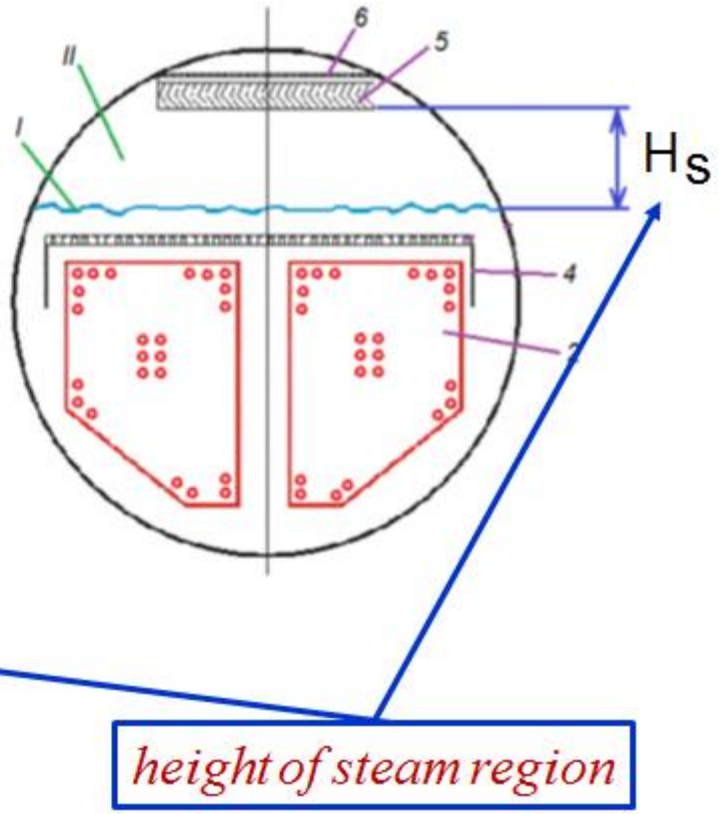
Additional determining factors:

- uniform loading of evaporation surface (superficial steam velocity);
- chemical composition of SG water

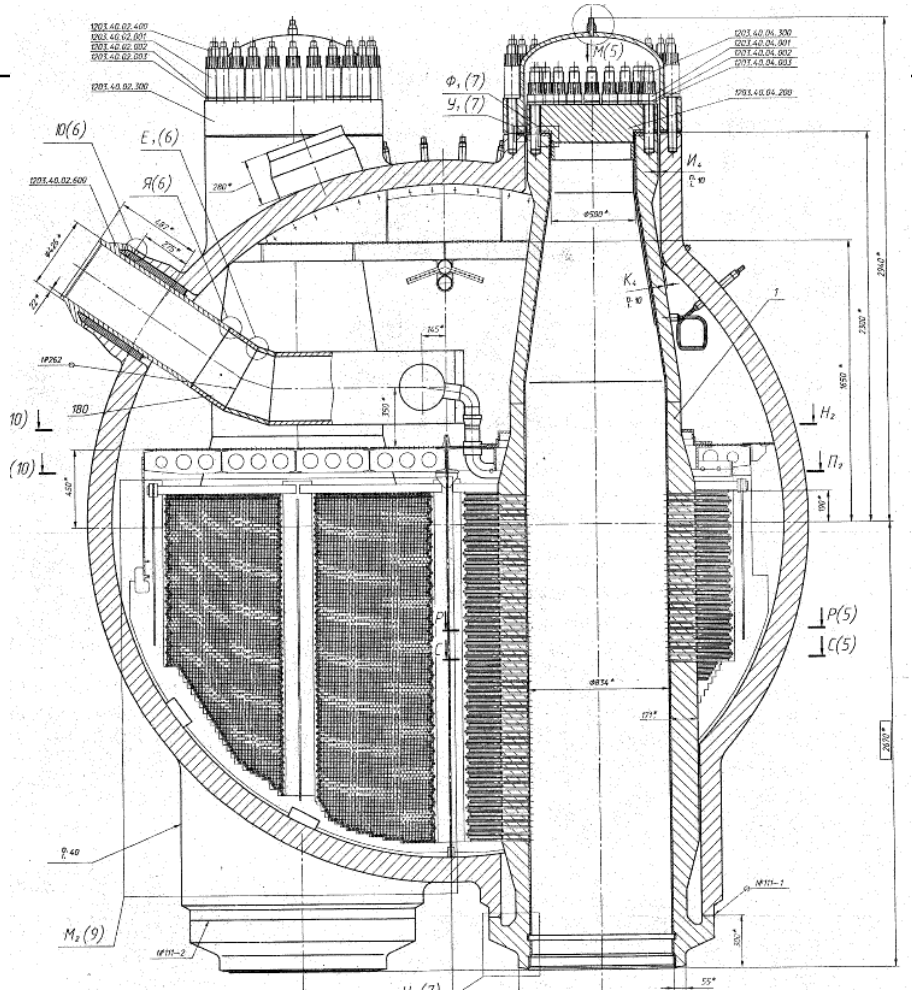
Note. *Superficial steam velocity w''_0 is the velocity of steam passage through the evaporation surface*

Dependence of moisture content of steam *y* on height of steam region H_s

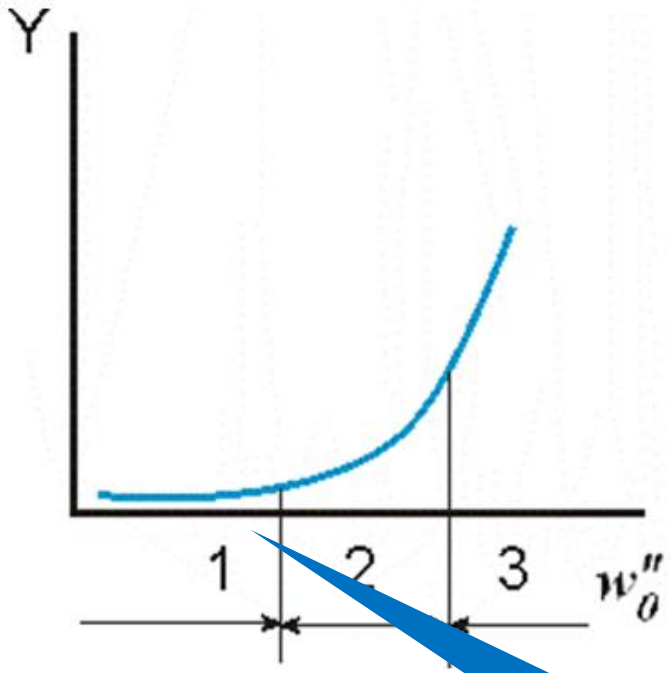




A cross-section of SG VVER



Dependence of moisture content of steam *y* on superficial steam velocity w_0''



1 - Y = 0…0,0003; m = 1…2,5
2 - Y = 0,0003…0,002; m = 2,5…4
3 - Y > 0,002; m = 8…10

Importantly. *Different values of coefficient m*

Operation region of modern WWER SGs

Formula of dependence of steam moisture content *y* on main determining factors

$$Y = M \cdot 10^{-4} \cdot \frac{\left(w_0''\right)^{2,76}}{H_S^{2,3}}$$

Here

$$M = 2,05 - 3,049 \cdot p + 0,9614 \cdot p^2$$

p in MPa

Submerged perforated plate (SPP)

Purpose – to provide uniform loading of evaporation surface

Position – 50…75 mm lower the mass water level

Perforation – holes of the diameter ≥ 10 mm

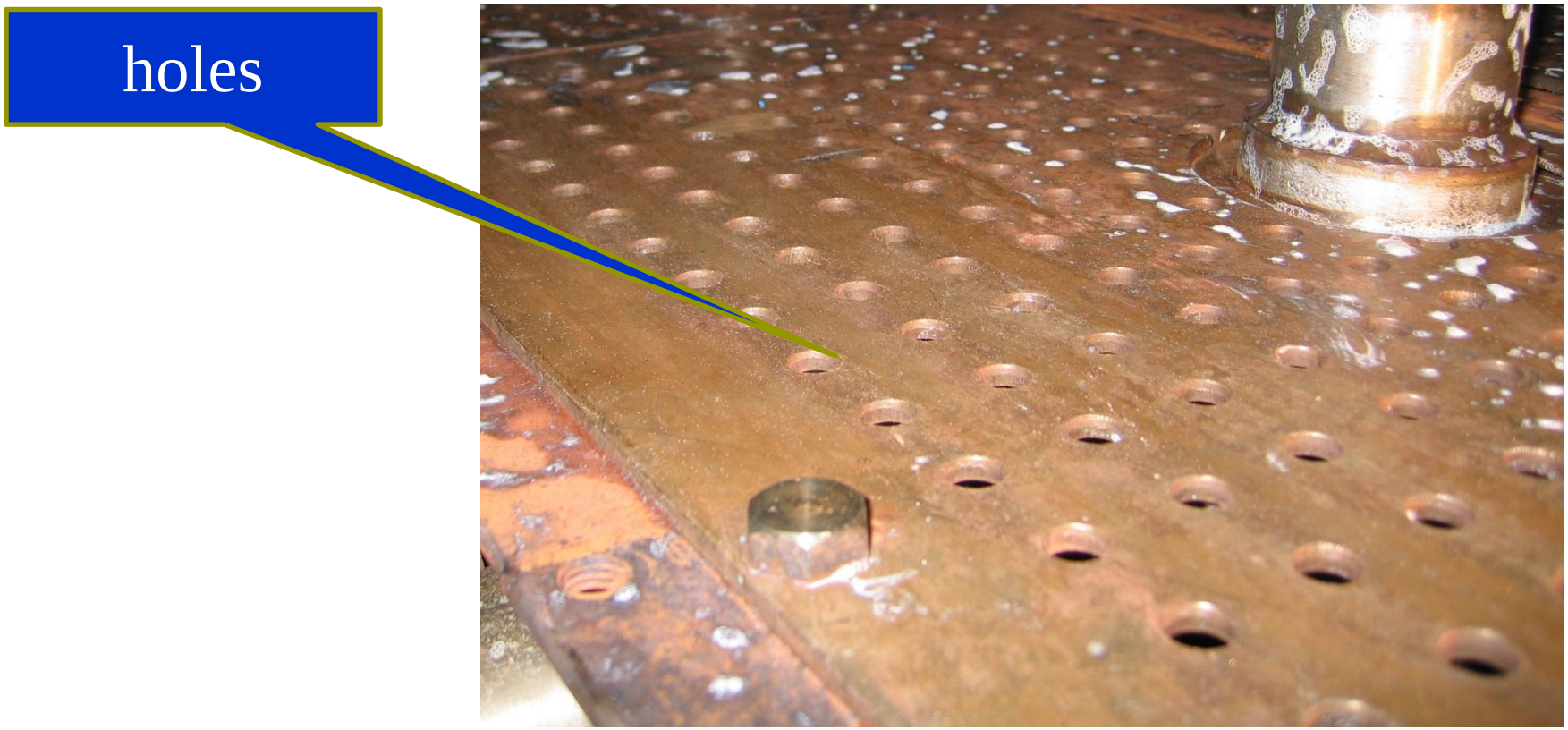
Compulsory elements – flanges

Flanges

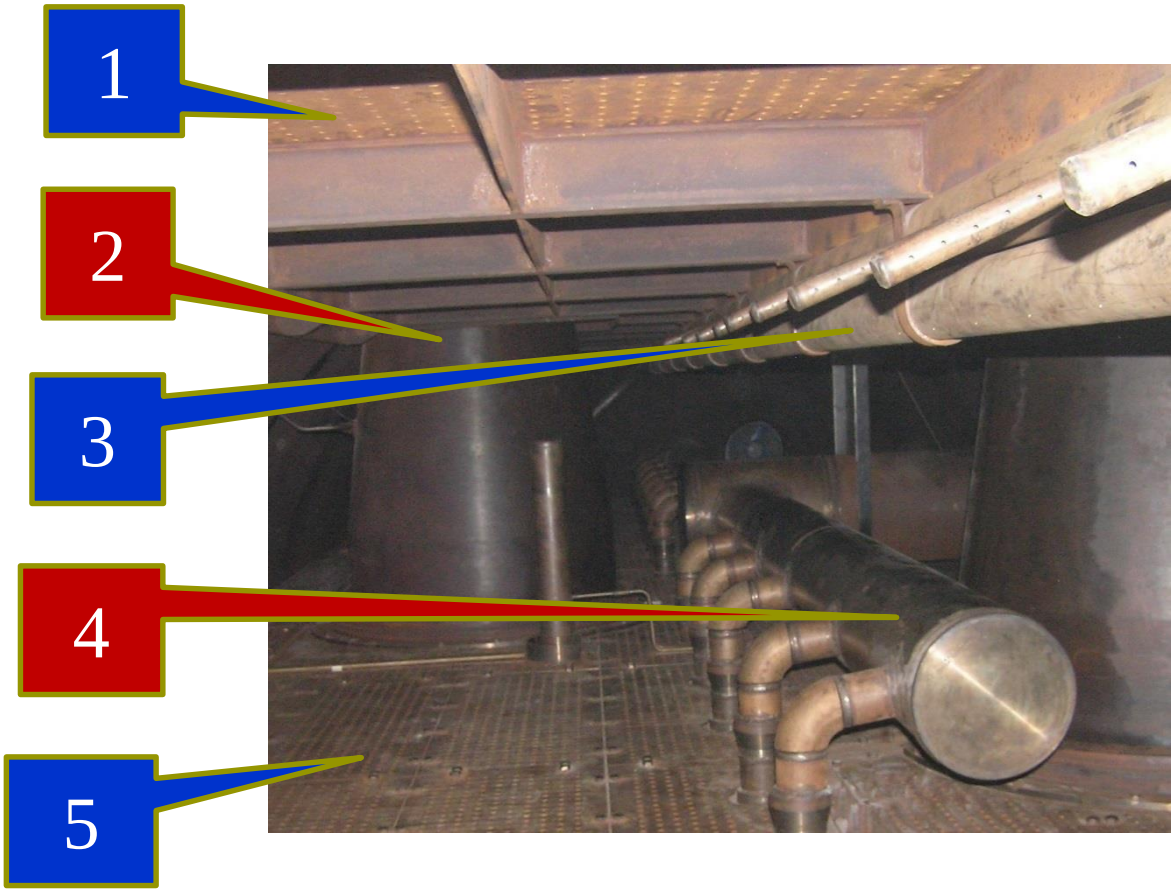
flanges

It looks like the edges of a tablecloth

Perforation



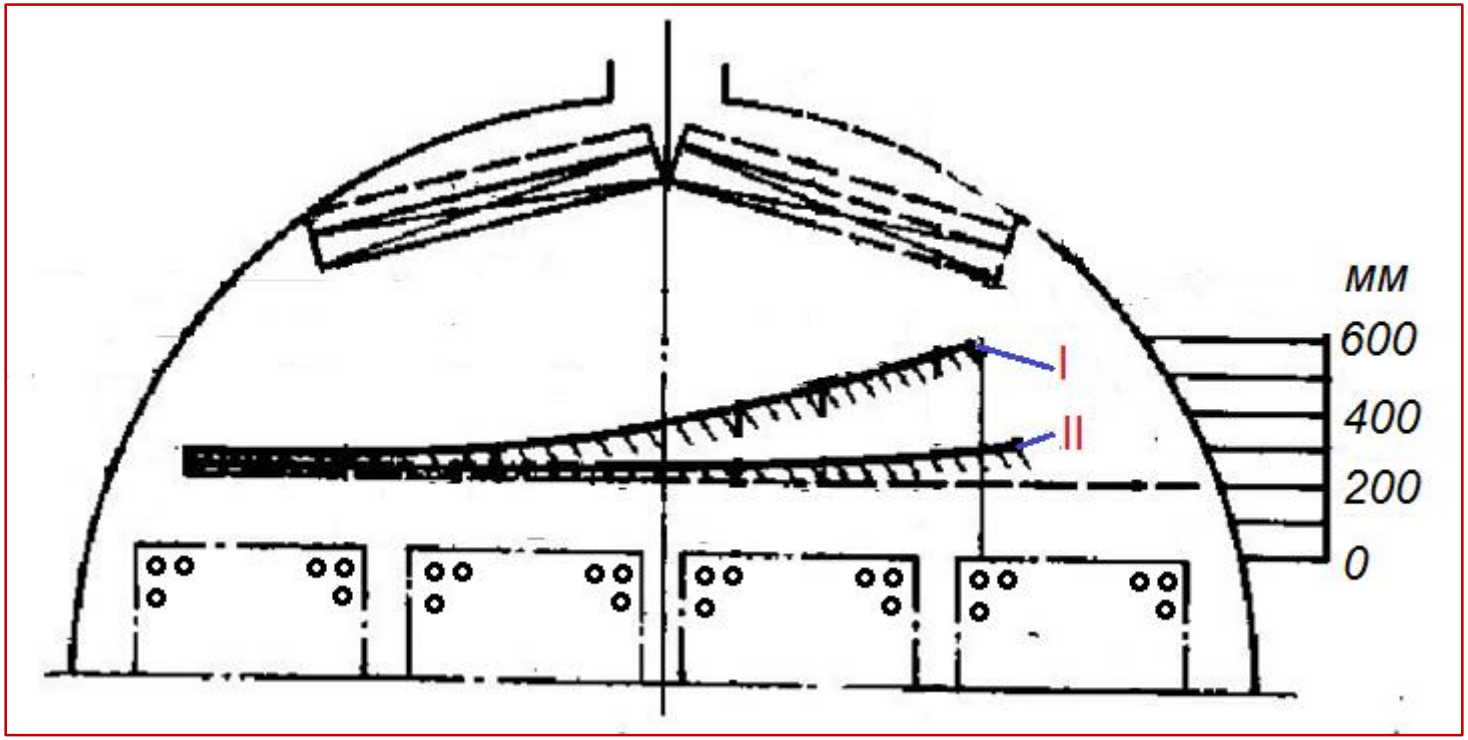
Steam generator elements



TIPs

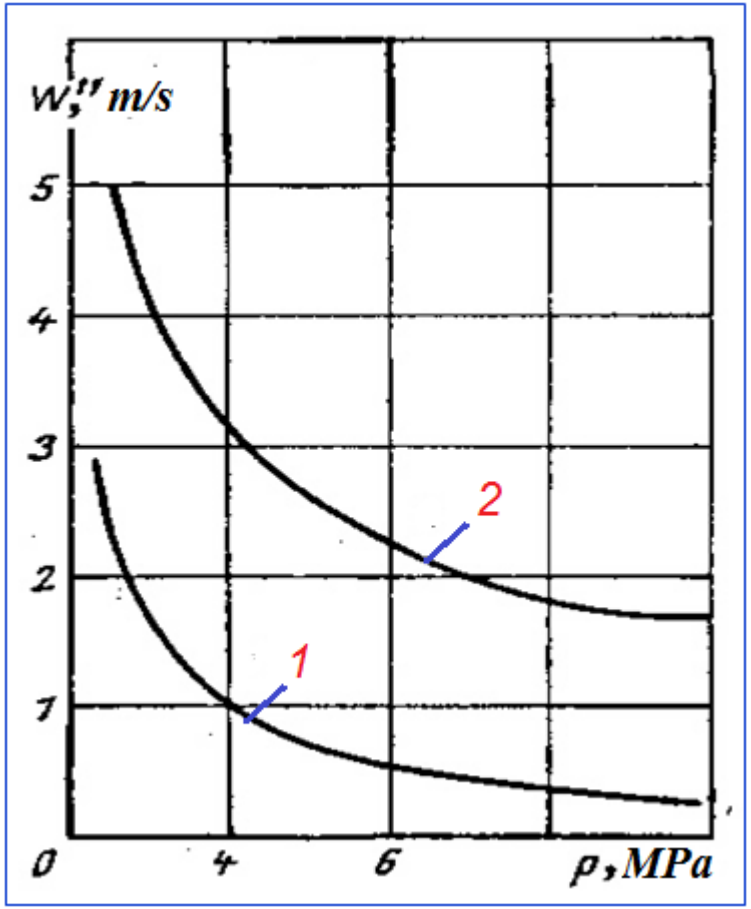
- feedwater supply collector;
- submerged perforated plate;
- emergency feed water collector;
- steam-receiving perforated plate;
- coolant collector (header)

Effect of SPP on positioning of actual water level in SG



II – SG with submerged perforated plate (SPP); I – without SPP

Steam velocity in SPP holes

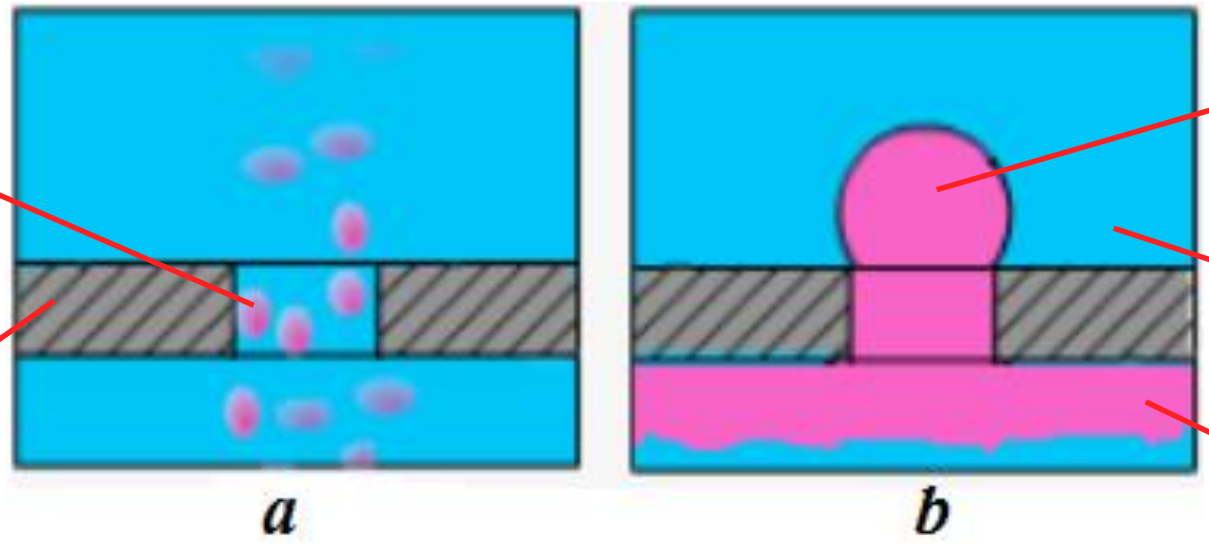


Dependences of steam velocity in SPP holes on pressure

1- minimum

2- recommended

Modes of operation of SPP



bubbles

SPP

bubble

water

steam blanket

The submerged perforated plate should work with a steam blanket (*b*)

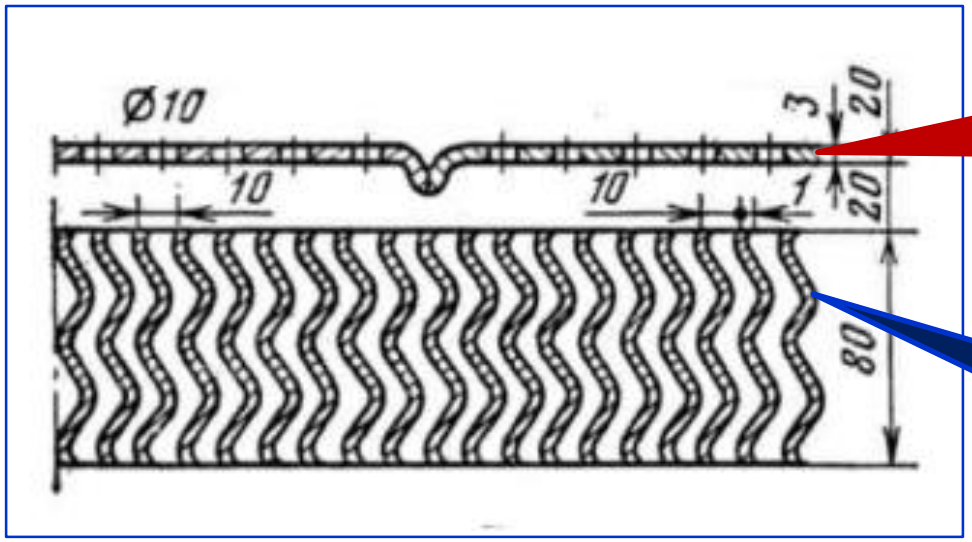
Louvre separators

Based on design peculiarities louvre separators are divided into:

- horizontal louvre separators;
- inclined louvre separator;
- vertical louvre separators

Horizontal louvre separator (screen drier)

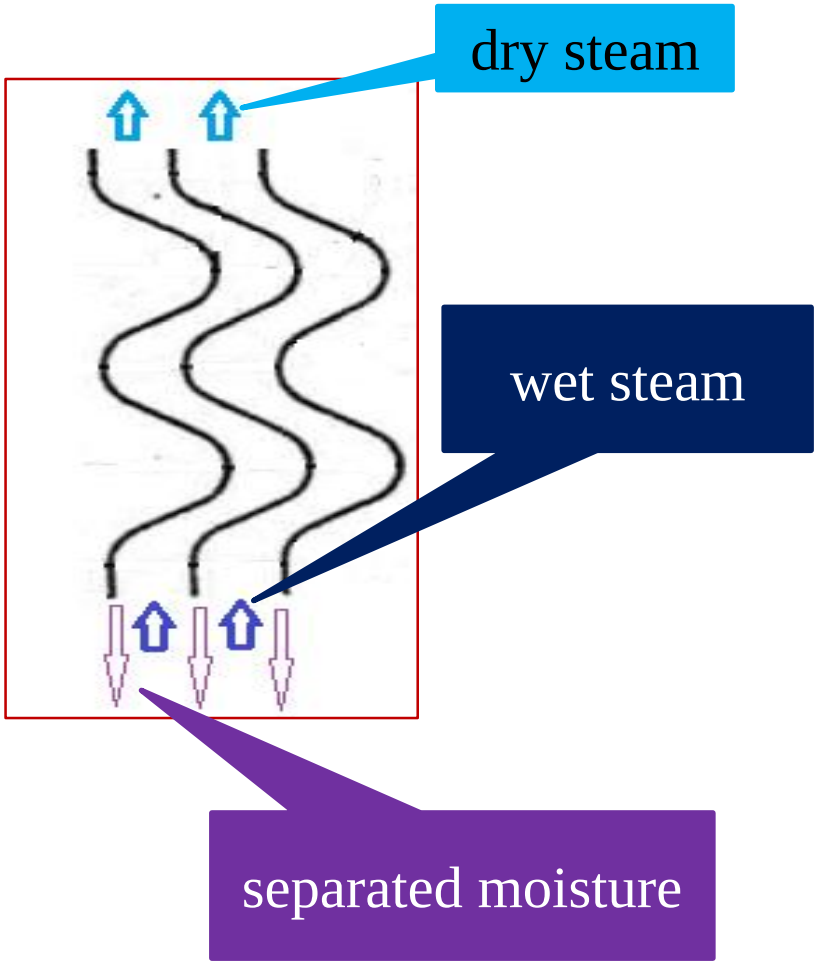
Horizontal louvre separator represents an array of waved plates of 1 mm thickness, 80…100 mm width.



steam-receiving ceiling (perforated plate)

packs of waved plates (chevrons)

Operating principle of horizontal louvre separator



Waved channels provide for centrifugal effect, which results in liquid precipitation on the surface of separator plates.

Separated liquid flows down the plate surface.

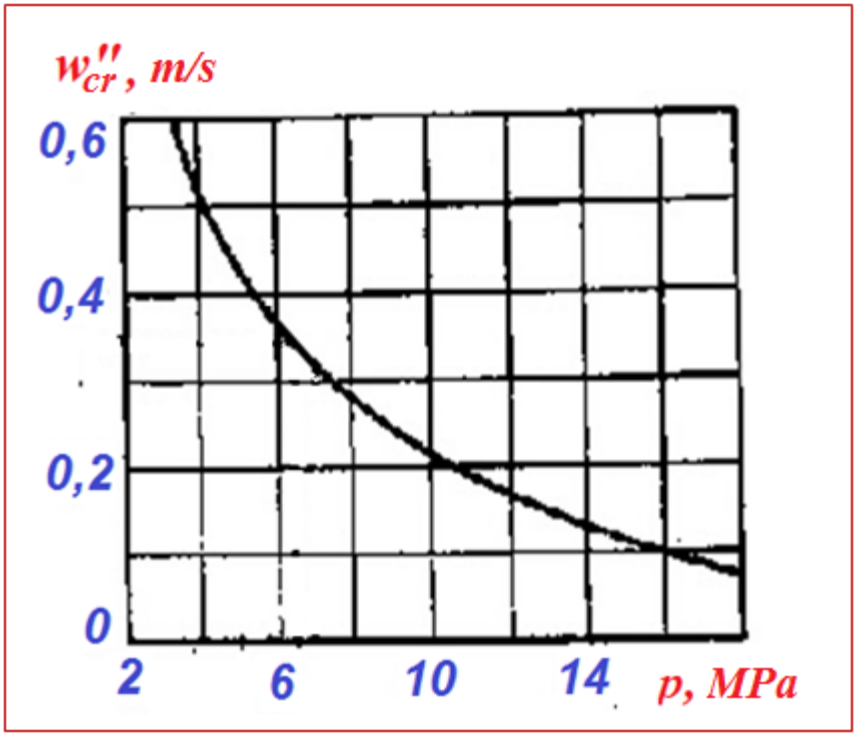
Dried steam moves upwards.

Efficiency of louvre separators

Main factors that determine the efficiency of louvre separators:

- steam velocity w'' at the entry of louvre separator;
- moisture content of steam at the entry of louvre separator (not more than 4…5 %)

Efficiency of louvre separators



Critical steam velocity at the entry of horizontal louvre separator

Advantages and disadvantages of louvre separators

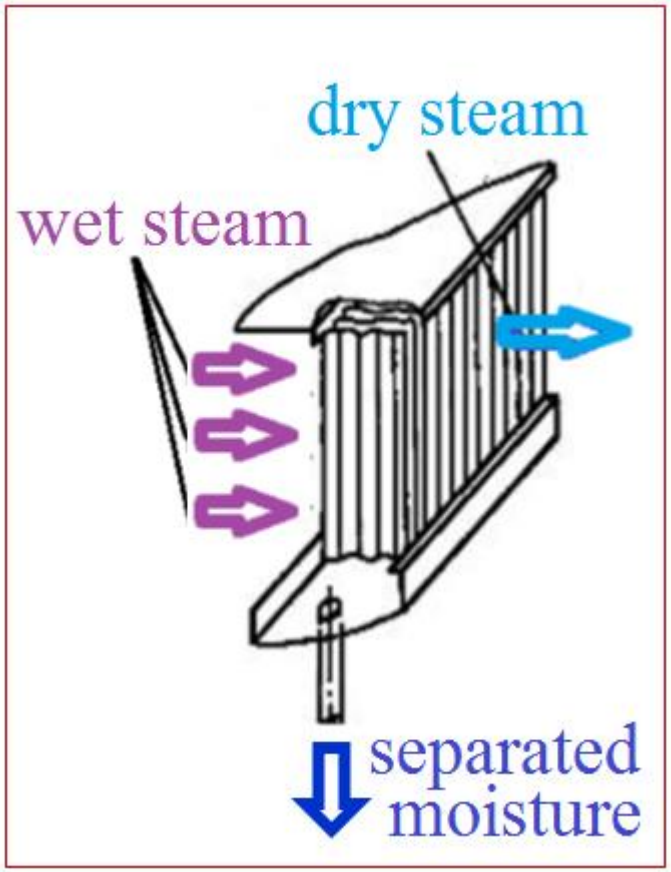
Advantages:

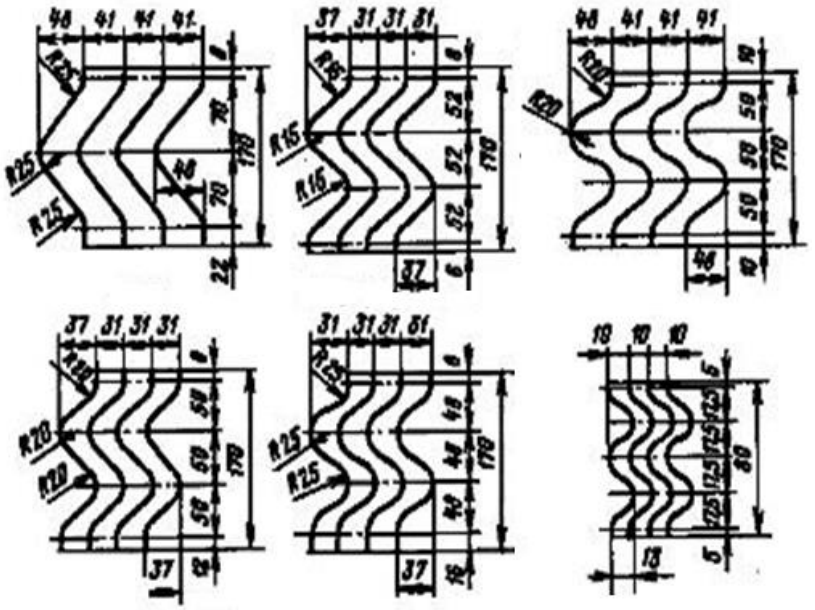
- high efficiency of steam drying;
- high operation reliability;
- low hydraulic resistance;
- design, manufacture, and installation simplicity.

Disadvantages:

- metal-intensiveness;
- complicated removal of separated water

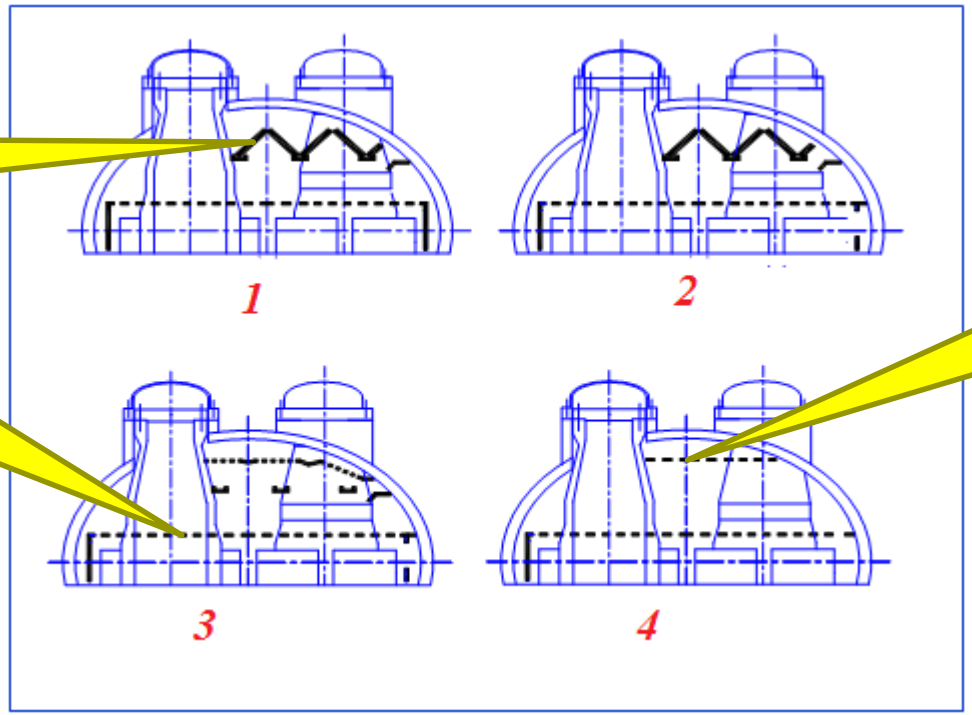
Schematic designs of vertical louvre separator





Types of separation elements of vertical louvre separators

Alteration of separation scheme of PGV-1000



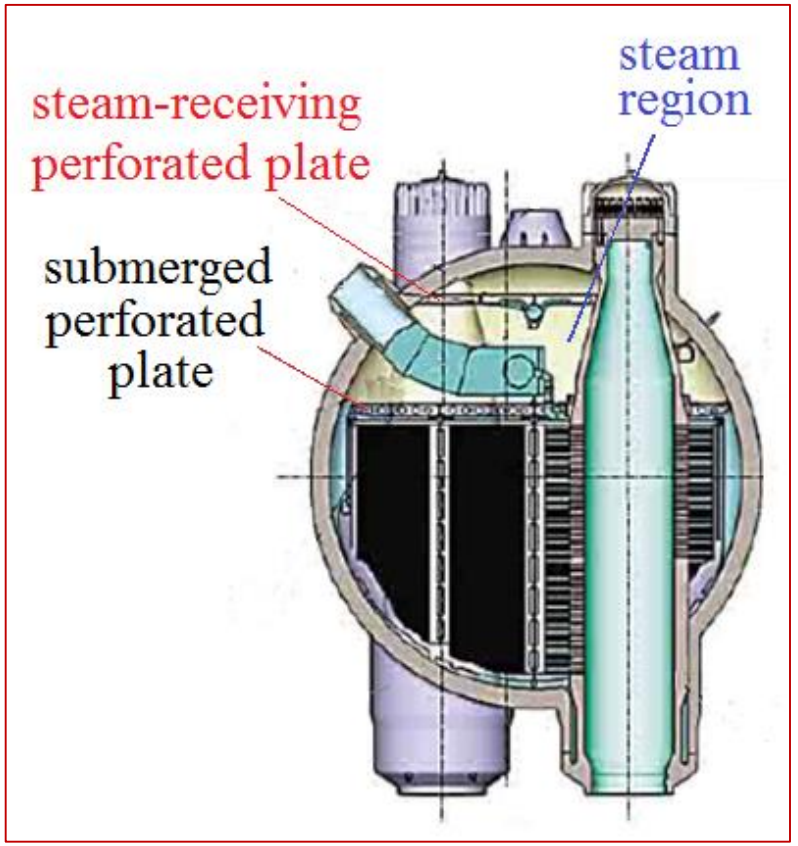
1- initial scheme with chevrons; *2*- channel is closed on the hot side;

3- chevrons are removed; *4*- new scheme

Alteration of separation scheme of PGV-1000

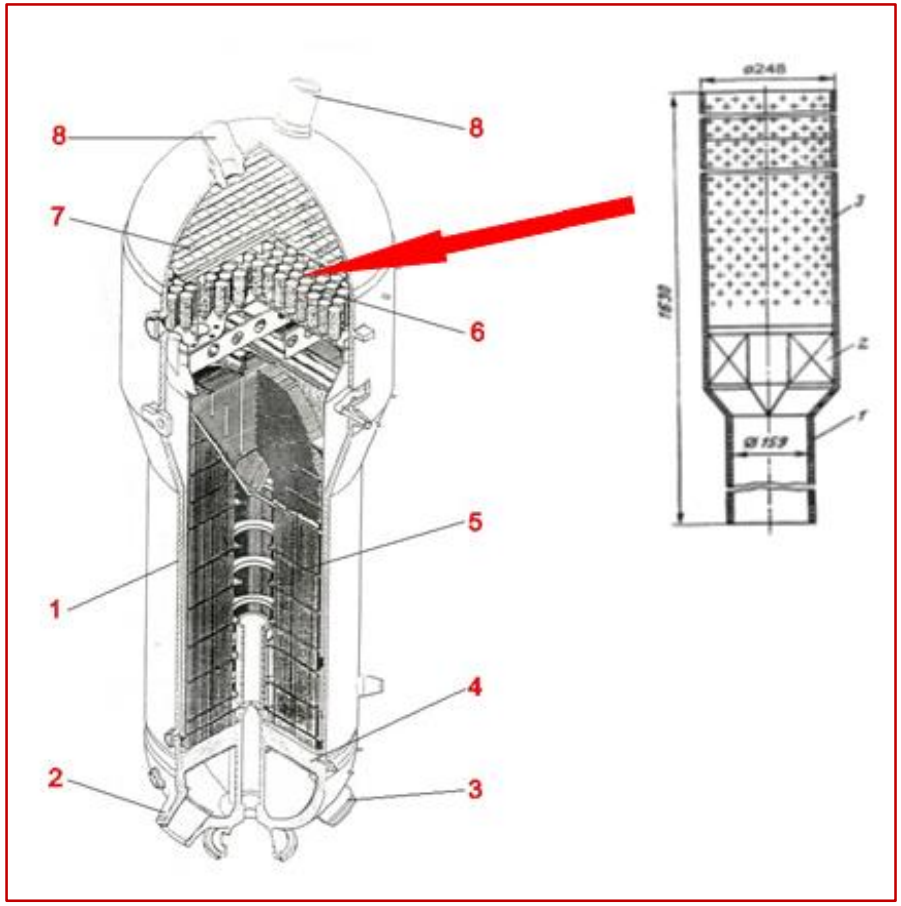
New projects of WWER SGs employ only gravitational separation.

Steam-receiving perforated plate (SRPP) is applied instead of louvre separator. For steam load equalization of evaporation surface a submerged perforated plate (SPP) is used.

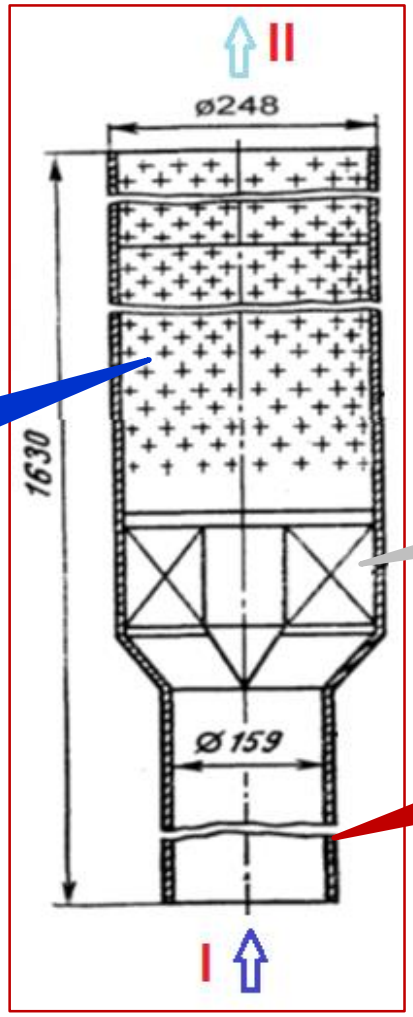


Centrifugal separators

Nowadays, centrifugal separation devices (cyclones) are applied in vertical SGs of PWR NPPs.



Design of axial centrifugal separator for vertical SG



I - steam-water mixture inlet;

II – wet steam outlet

vessel with holes

swirlers

supply nozzle

Operating principle of centrifugal separator

Steam-water mixture is supplied to the inlet nozzle and, then, to the vane swirler where it is given a swirling motion.

Water is thrown onto the walls of the separator vessel by centrifugal force and is removed from the separator through holes.

Steam travels from the separator to the steam region.

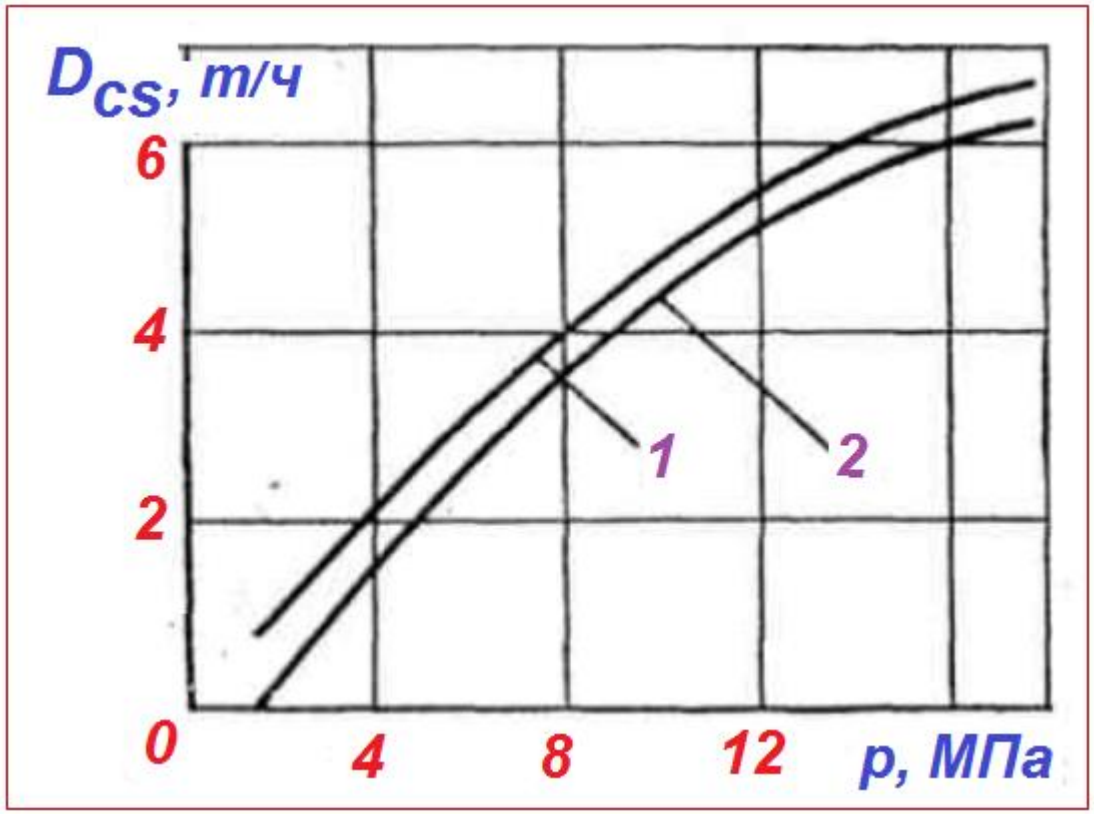
Separators are fixed on the plate over the tube bundle.

Conditions for effective operation of centrifugal separators

Normal operation of a cyclone depends on the correct selection of steam flow rate.

Steam flow rate for a typical size cyclone is standardized.

Recommended loading of a single cyclone of 290 mm diameter



1 – normal; 2 – minimum

Advantages and disadvantages of centrifugal separators

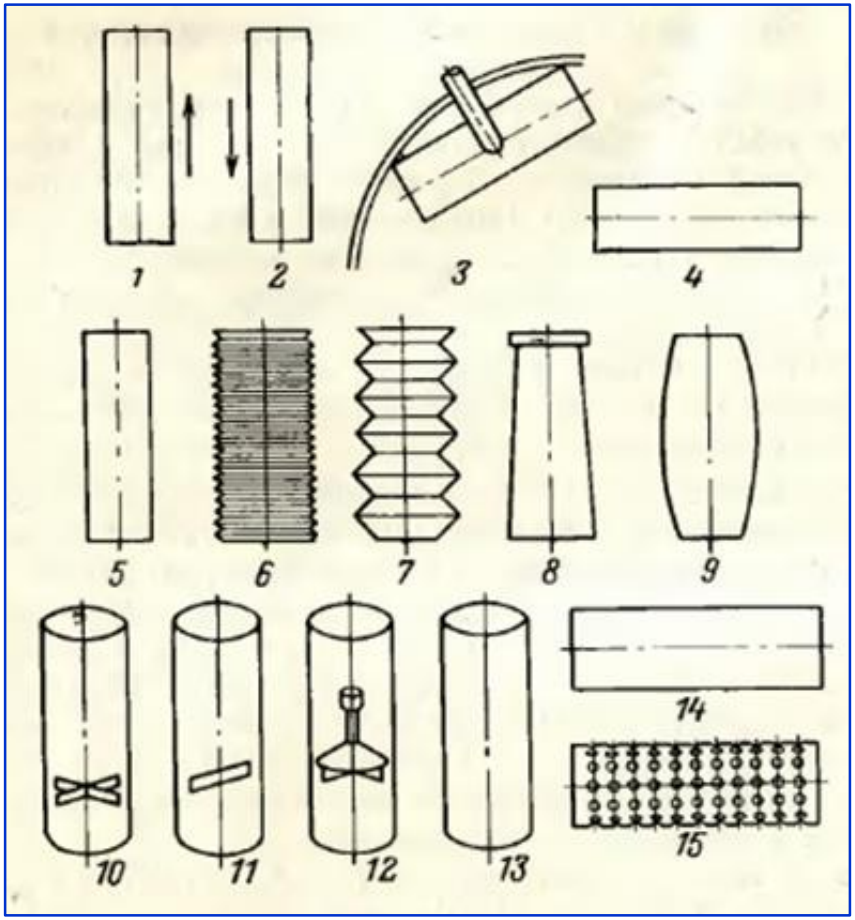
Advantages:

- compactness;
- effectiveness.

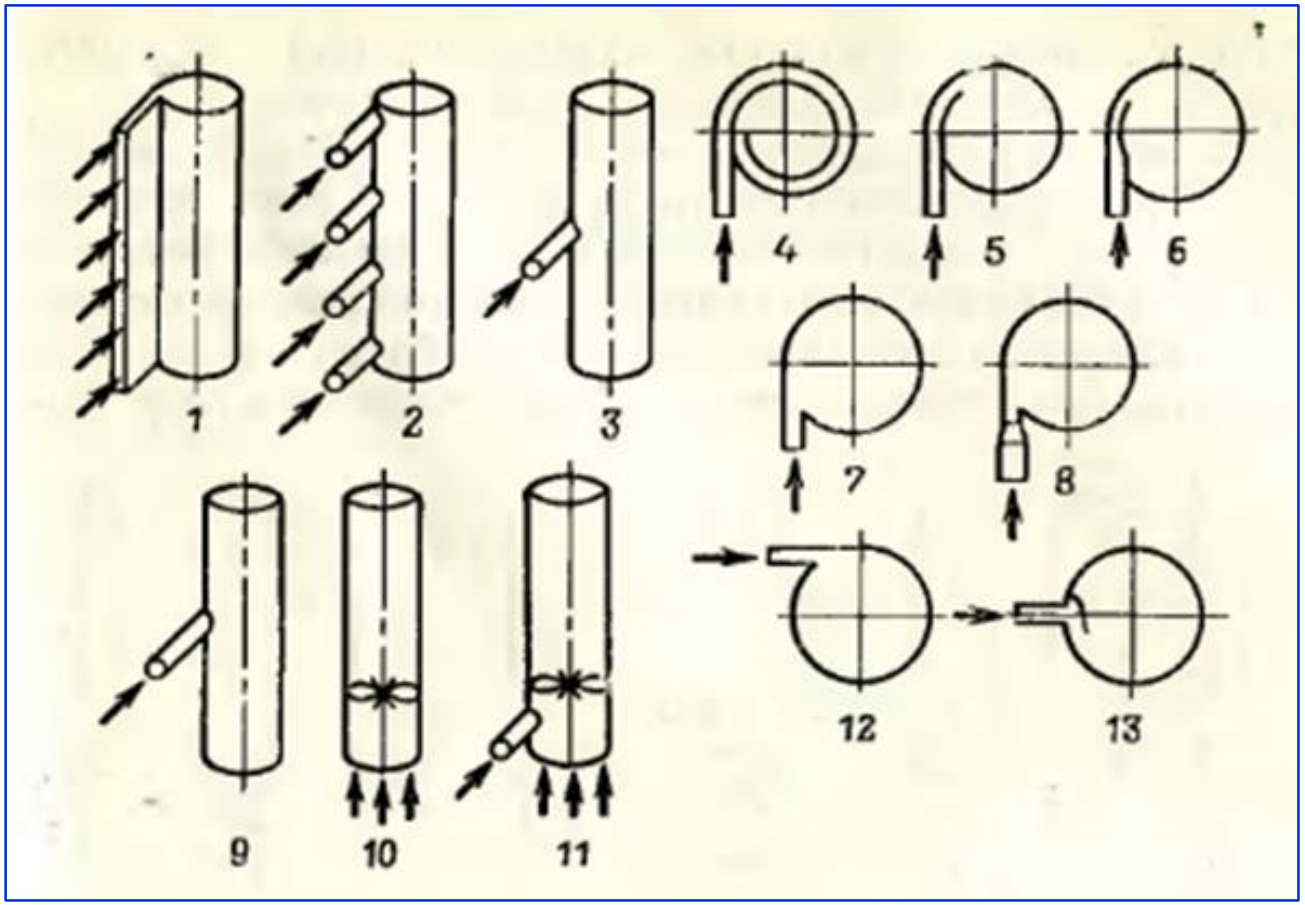
Disadvantages:

- considerable hydraulic resistances

Vessels of centrifugal separators



Mixture inlet in centrifugal separators



Thank you for attention