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Power supply

Lecture No 4

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Lecture 4.
Hydraulic calculation of water heating systems

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Content of Lecture No 4

1. Pressure calculation in water heating systems;
2. Types of hydraulic calculation.

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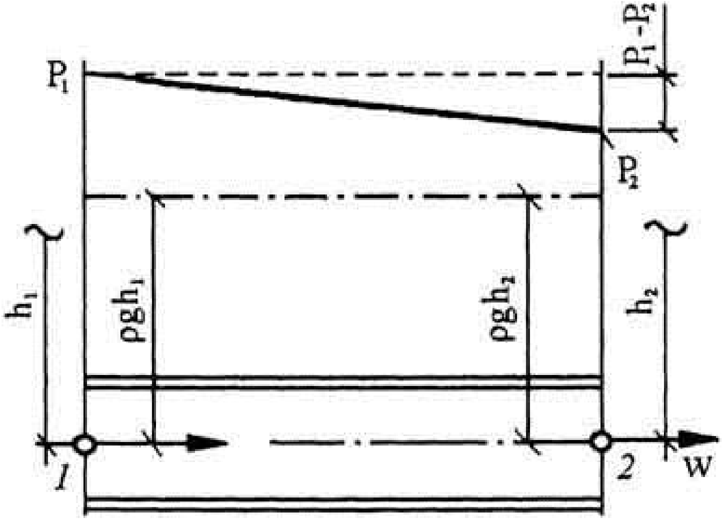
Changing the pressure in the heating system is considered to identify places with extremely low or high pressure causing a disturbance of water circulation or the destruction of individual elements of the system.

1. Change in pressure during water movement in pipes

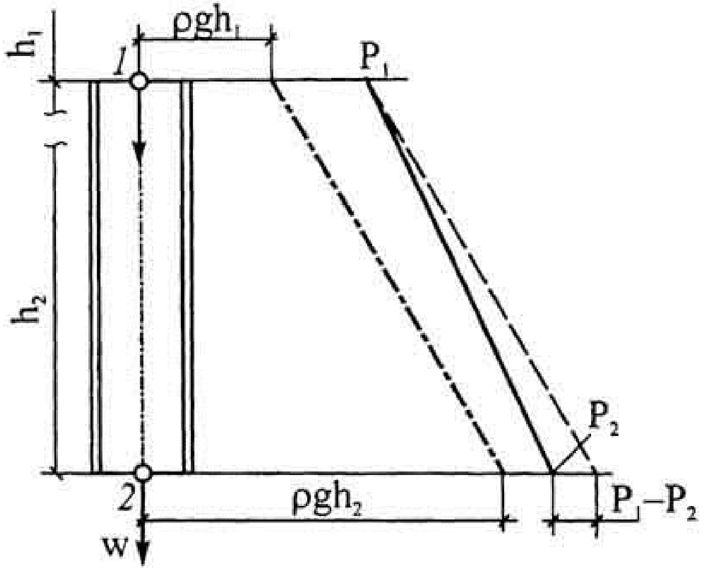
Total pressure according to Bernoulli's equation: $P = \rho w^2 / 2 + \rho g h + p_s$

hydrodynamic pressure

hydrostatic pressure

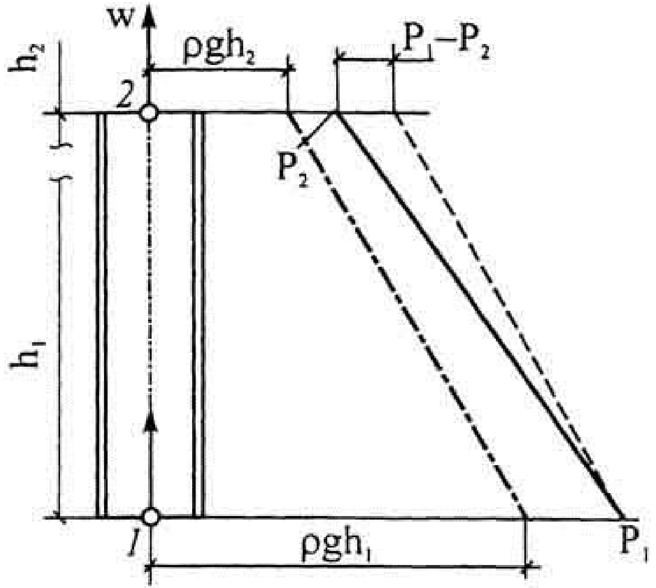


The change in hydrostatic pressure in a horizontal pipe during water movement with a constant velocity (pressure diagram over the pipe): 1 and 2 - the initial and final sections of the flow; h is the vertical distance from the flow axis to the free surface of the water (upper water level in the open expansion tank).



The change in hydrostatic pressure in a vertical pipe during water movement from top to bottom (pressure diagram to the right of the pipe): 1 and 2 - the initial and final sections of the flow; h is the vertical distance from the flow cross-section to the free water surface.

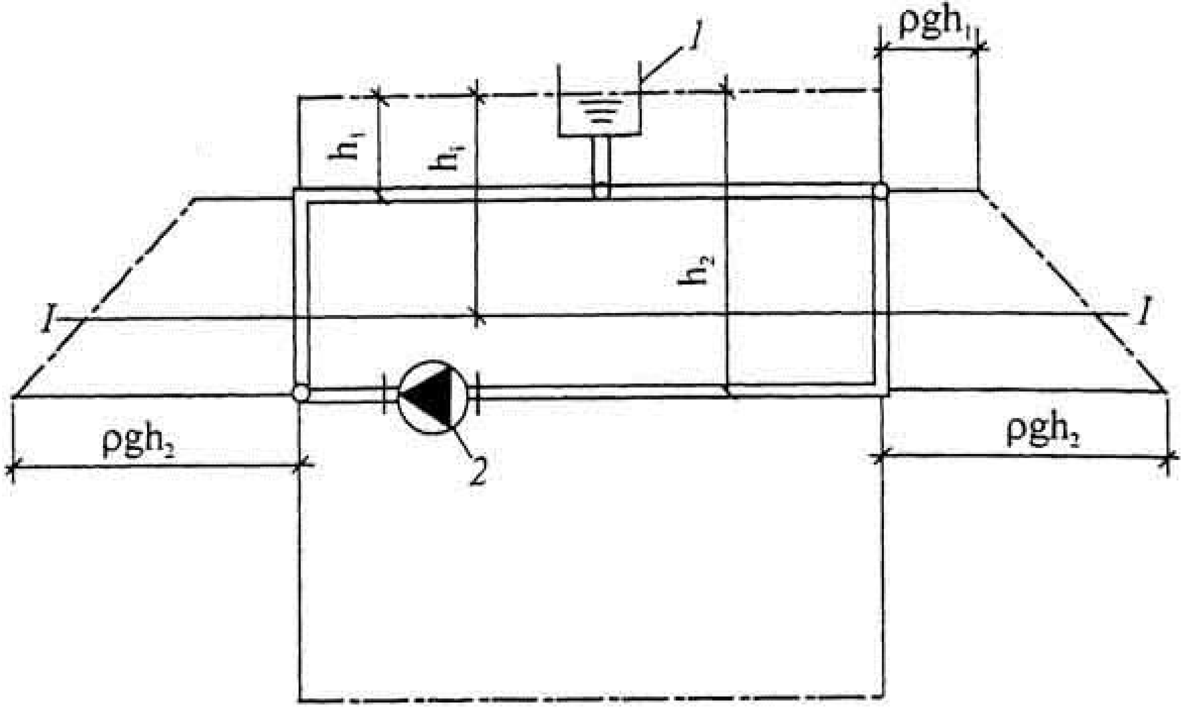
ρgh2 + p2>ρgh1+p1.



The change in the hydrostatic pressure in the vertical pipe during water movement from bottom to top (the pressure diagram to the right of the pipe)

ρgh1 + p1> ρgh2 + p2

Pressure dynamics in water heating system with open expansion tank



Closed circuit of the heating system is represented by double lines

Diagram of hydrostatic pressure in a heating system with unheated water when the circulating pump is not operating:
1 - an open expansion tank; 2 - circulating pump.

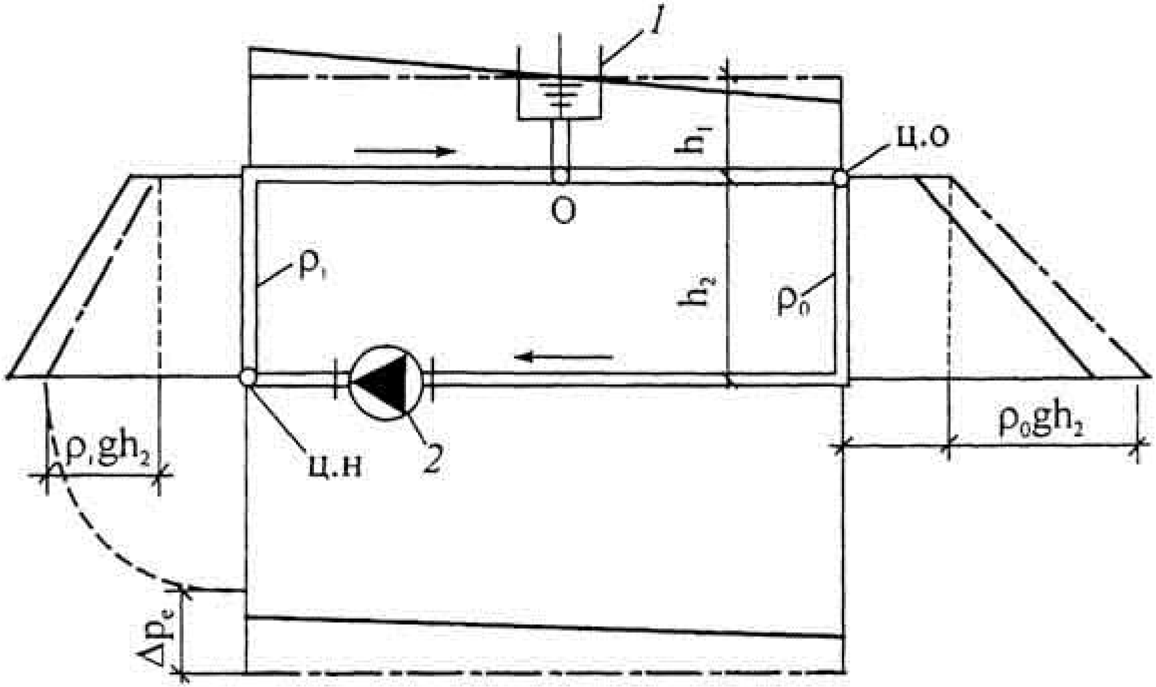


Diagram of hydrostatic pressure in a heating system with heated water when the circulating pump is not operating: 1 - an open expansion tank; 2 - circulating pump; ц.н - heating center; ц.о is the cooling center; O - constant pressure point.

$$\Delta p_e = \Delta p_c.$$

Pressure losses in the system

The maximum hydrostatic pressure at the bottom point of the right riser with cooled water:

$$g(\rho_r h_1 + \rho_o h_2),$$

The maximum hydrostatic pressure at the bottom point of the left riser with heated water:

$$g(\rho_r h_1 + \rho_r h_2).$$

The natural circulation (gravity) pressure:

$$\Delta p_e = \rho_o g h_2 - \rho_r g h_2,$$

or

$$\Delta p_e = gh(\rho_o - \rho_r),$$

h2 is the vertical distance between the centers of cooling and heating of water or the height of two columns of water - a chilled and heated

The total pressure loss due to water movement in the closed ring of the heating system:

$$\Delta p_c = \Delta p_{наг} + \Delta p_{вс}.$$

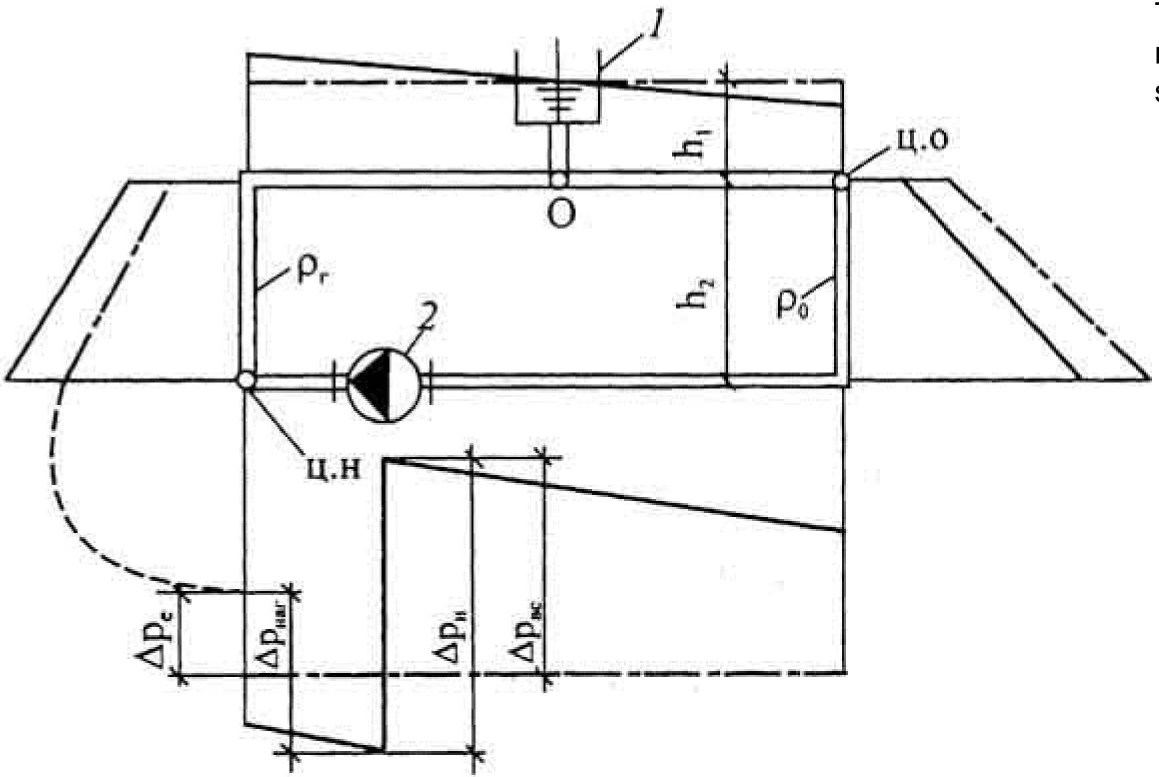
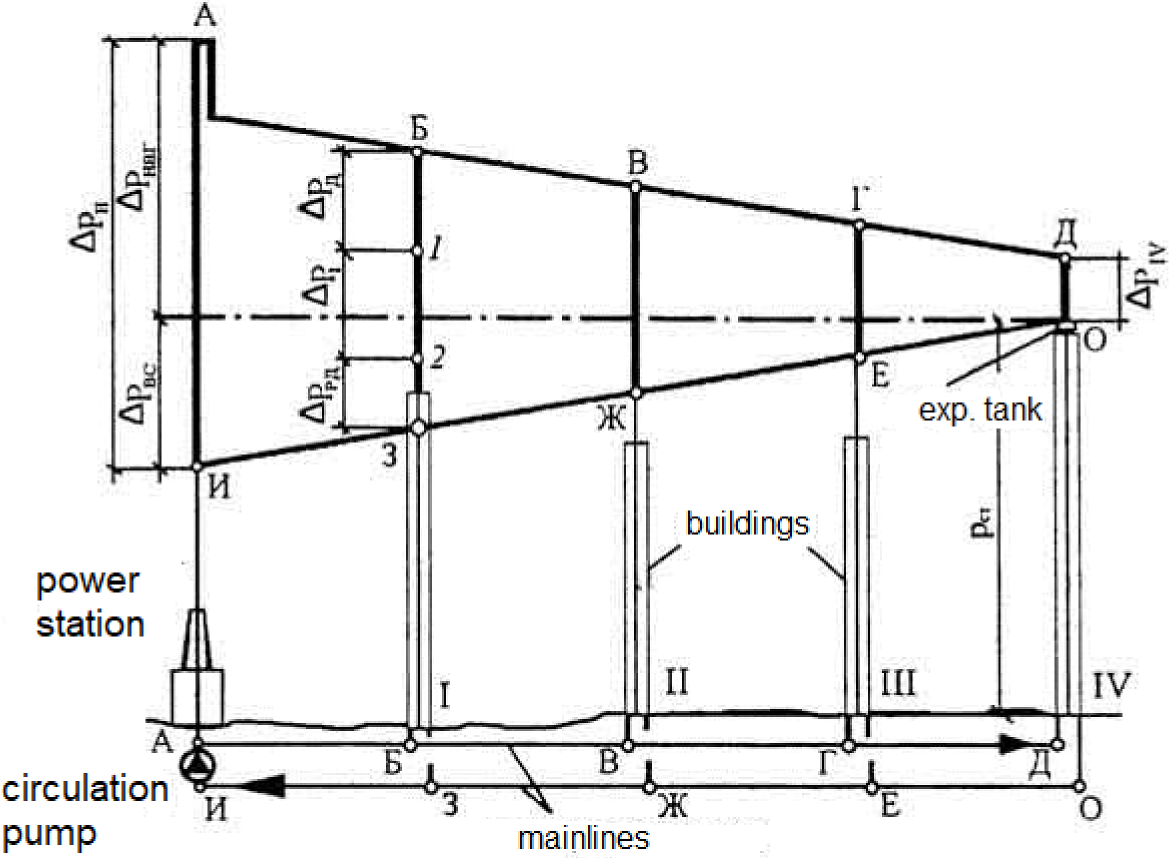


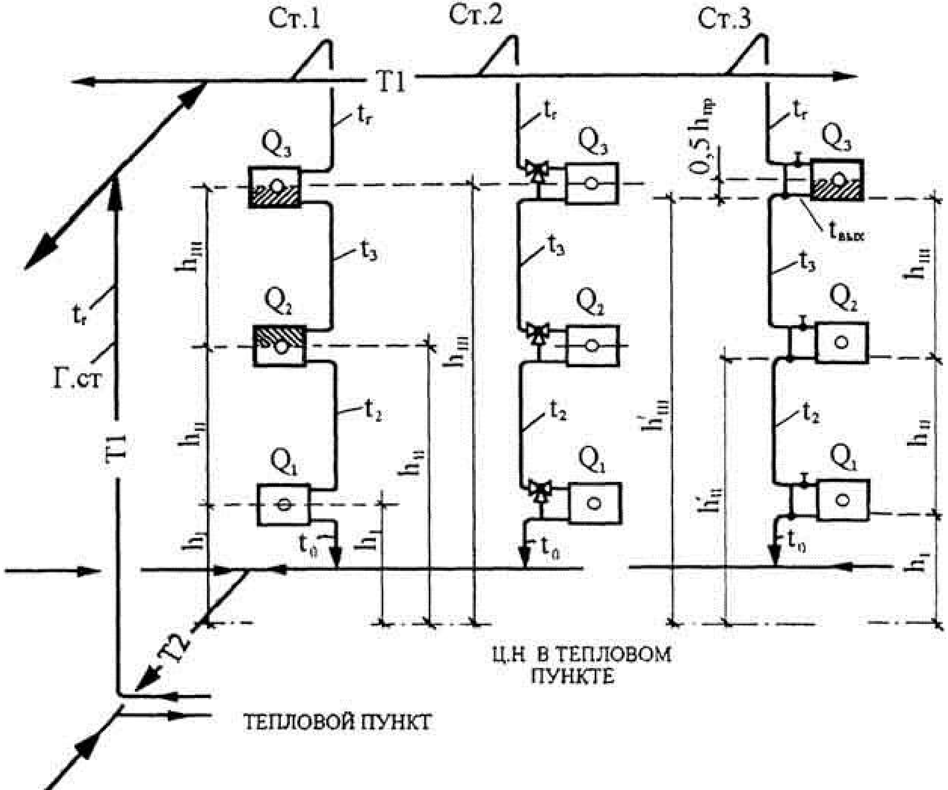
Diagram of hydrostatic pressure in a heating system with heated water and operating circulation pump (solid lines).

Heating system for district (4 buildings) with expansion tank



Calculation of natural circulation pressure in water heating system

- For vertical one-pipe system with top laying of main line



$$\Delta p_{e.пр} = (\beta g / (cG_{ст}))\sum_{1}^{N}(Q_i\, h_i)\, \beta_1\beta_2,$$

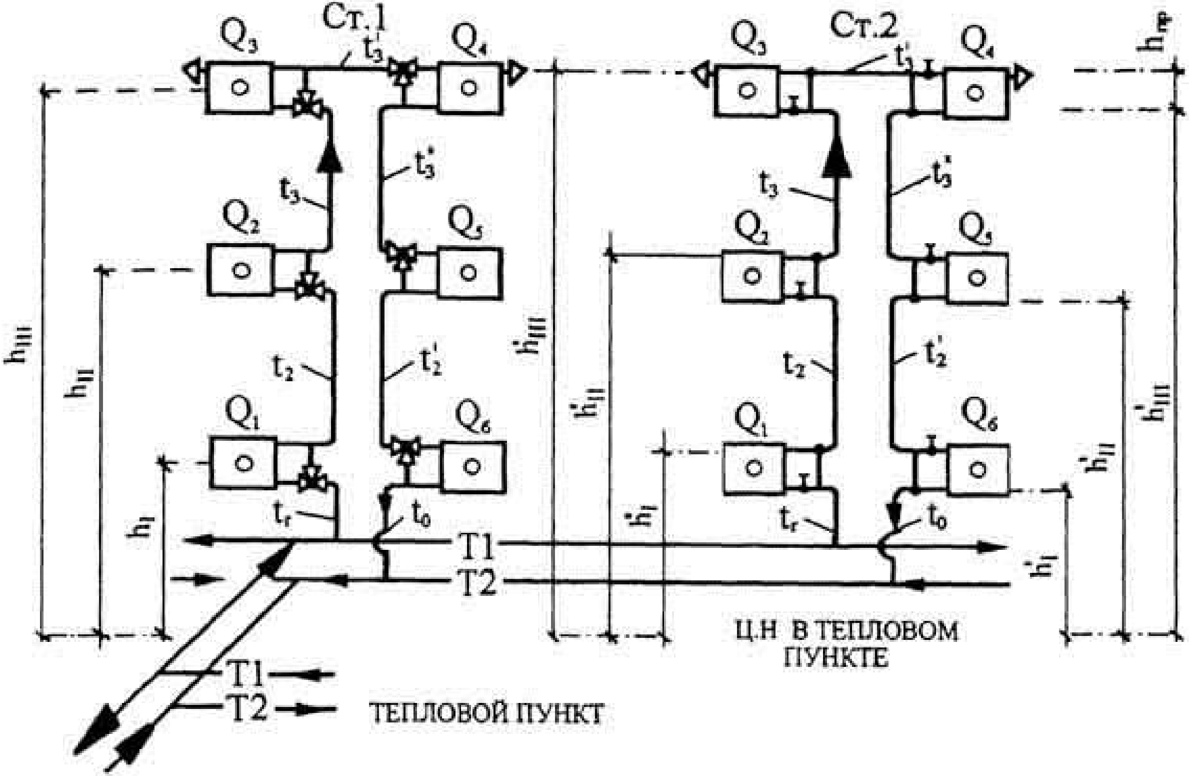
where an average decrease in density with increasing temperature by 1°C:

$$\beta = (\rho o - \rho г) / (to – tг), kg/(м^3 \cdot °C);$$

N – number of heaters in a riser;
Qi hi is the product of the heat load of the i-th heater by the vertical distance h, - from its cooling center to the heating water center in the heating system.

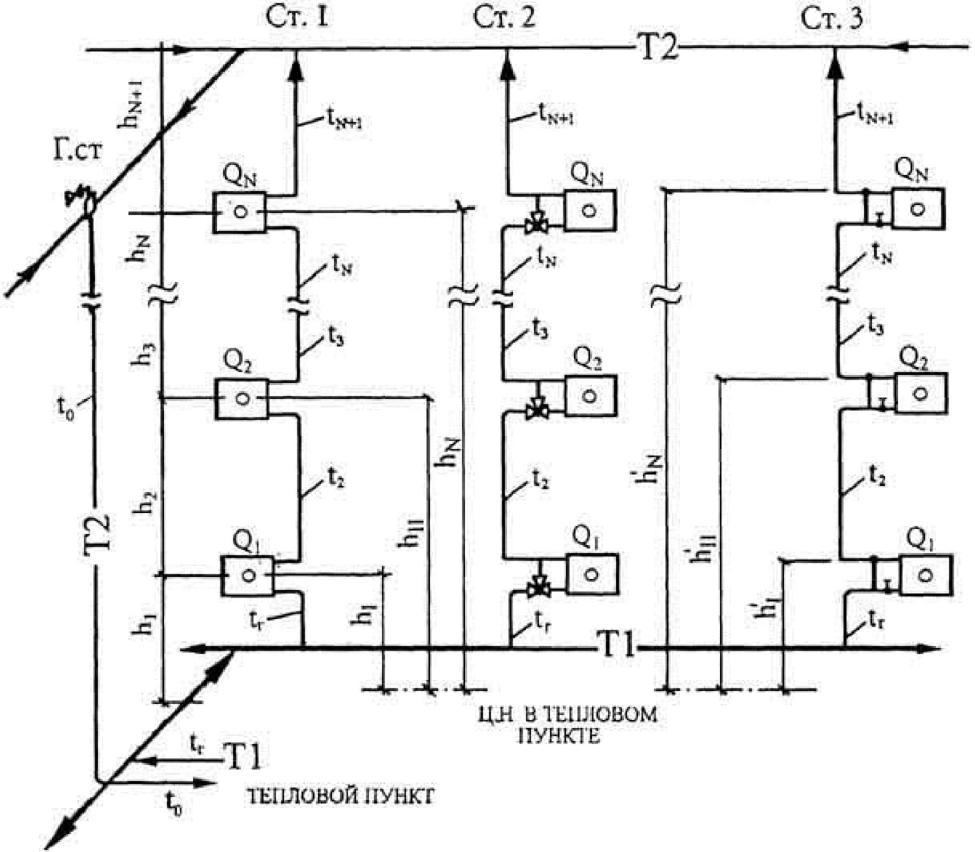
β1 - correction factor, taking into account heat transfer through the additional area (in excess of the calculated) of the heater (for radiators and convectors β1 = 1.03 ... 1.08, for ribbed pipes β1 = I, 13);
β2 - correction factor that takes into account additional heat losses due to the placement of heaters at external fences (a sectional radiator or convector of types KN and KO - β2 = 1,02, KA convector - 1,03, panel radiator - 1.04).

- For vertical one-pipe system with lower laying of main lines



The same general equation as in previous case

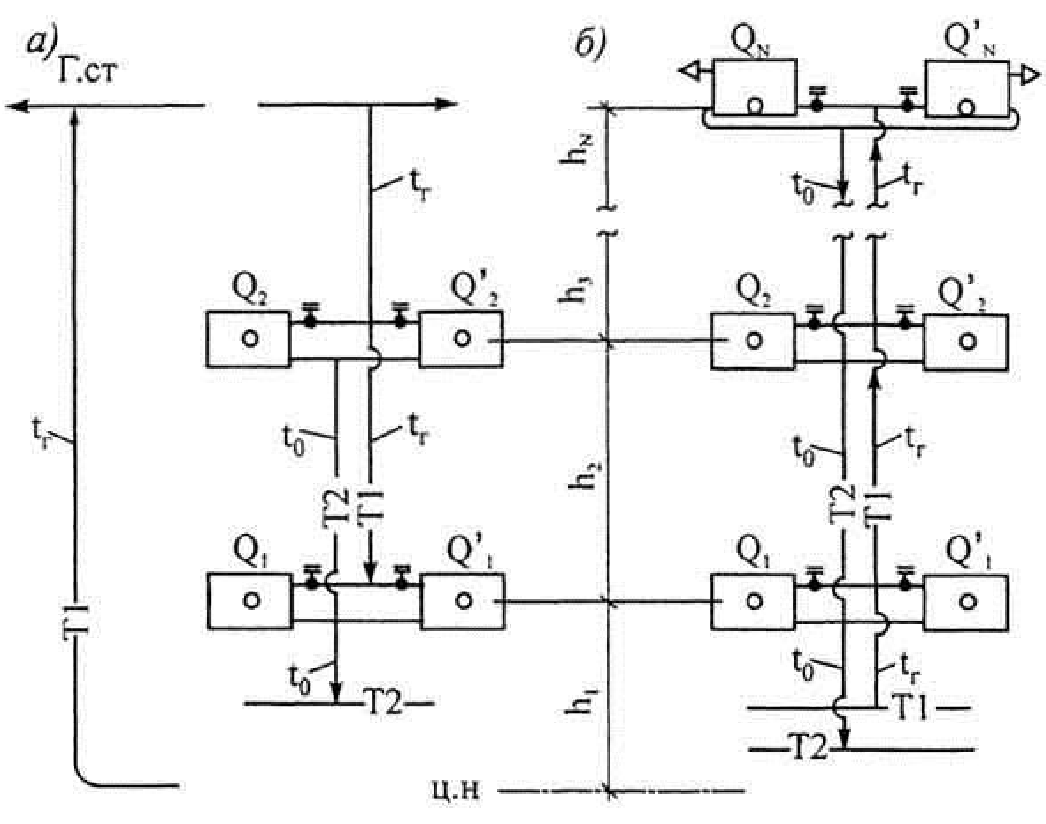
- For vertical one-pipe system with reverse circulation (when the flow line is placed in the basement, and return line in the attic)



For N-floors buildings:

$$\Delta p_{e.пр} = g(h_{N+1}(\rho_o - \rho_{N+1}) + h_N(\rho_o - \rho_N) + \ldots$$
$$\ldots + h_2(\rho_o - \rho_2) + h_1(\rho_o - \rho_г)).$$

- For vertical two-pipe system (a - with top laying of flow line, b - with lower laying of main lines)



Natural circulating pressure in circulating rings through the heaters on the first floor:

$$\Delta p_{e.пр.I} = gh_1(\rho_o - \rho_г),$$

through the heaters on the second floor:

$$\Delta p_{e.пр.II} = g(h_1 + h_2)(\rho_o - \rho_г),$$

through the heaters on the N-floor:

$$\Delta p_{e.пр.N} = g(h_1 + h_2 + \ldots + h_N)(\rho_o - \rho_г).$$

- For horizontal one-pipe system

with a branch having axial closing sections on the third floor:

$$\Delta p_{е.мал} = gh'(\rho_{вых} - \rho_{вх}),$$

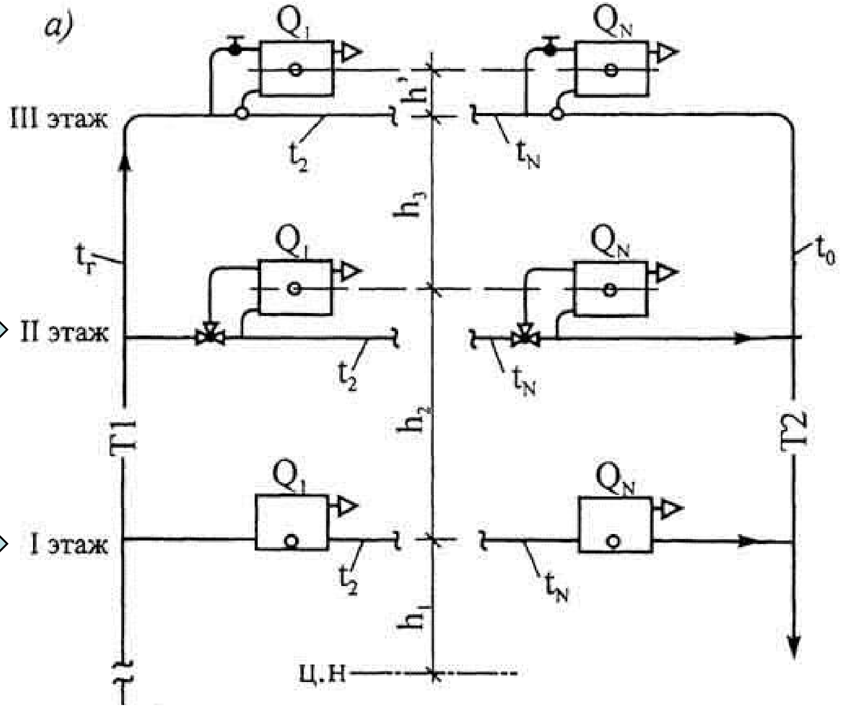
h 'is the vertical distance between the centers of water cooling in the device and in the branch

with a flow-regulated branch on the second floor:

$$\Delta_{pe.пр.II} = g(h_1 + h_2)(\rho_o - \rho_г)$$

with a flowing branch on the first floor:

$$\Delta_{pe.пр.I} = gh_1(\rho_o - \rho_г);$$



Calculated circulation pressure in pump water heating system

It is the value of the total circulation pressure, which is chosen to maintain the calculated hydraulic mode in the heating system. Calculated circulation pressure expresses the available pressure difference (pumping and natural), which under design conditions can be used to overcome the hydraulic resistance to water movement in the heating system.

General equation:

$$\Delta p_р = \Delta p_н + Б\Delta p_е$$

$$\Delta p_р = \Delta p_н + Б(\Delta p_{е.пр} + \Delta p_{е.тр}),$$

Б is the correction factor taking into account the value of the natural circulation pressure during the period of maintaining the calculated hydraulic regime in the system (Б≤1).

For vertical one-pipe systems Б=1 : $\Delta p_р = \Delta p_н + \Delta p_е.$

For horizontal one-pipe, two-pipe systems Б=0,4 : $\Delta p_р = \Delta p_н + 0{,}4\Delta p_е.$

Hydraulic calculation is based on the principle: when the water flow is steady, the pressure difference (pump and natural) acting in the system is completely spent on overcoming the hydraulic resistance to movement.

Scheme of the heating system (in axonometric projection).

A section is a pipe or pipes with the same coolant flow rate.

The circulating ring of the system.

The heat load of the heater is taken equal to the estimated heat loss of premises Qп.

The heat load of the section Qy is made up of the heat loads of the devices serviced by the water flowing through the section:

$$Q_{уч} = \Sigma Q_п.$$

The water flow in the section at the calculated difference in water temperature in the system:

$$G_{уч} = Q_{уч}\beta_1\beta_2 / (c(t_г - t_о)),$$

Pressure losses at each section (Darcy–Weisbach equation):

$$\Delta p_{уч} = (\lambda / d_в) l_{уч} (\rho w^2 / 2) + \sum \zeta_{уч} (\rho w^2 / 2),$$

where λ is the coefficient of hydraulic friction determining the linear loss in hydrostatic pressure ($\rho w^2/2$, Pa); Iуч - length of the section, m; Σζуч - the sum of the local resistance coefficients (LRC) in the section, expressing local losses of hydrostatic pressure (LRC values are given in the reference literature); ρ and w are, respectively, the average density, kg / m3, and the speed of movement, m / s, of water in the section.

Coefficient of hydraulic friction depends on the type of the flow in the pipeline.

Types of hydraulic calculations

1. Using specific linear pressure loss.

$$\Delta p_{уч} = (\lambda / d_в)(\rho w^2 / 2) l_{уч} + \sum\zeta_{уч}(\rho w^2 / 2) = R l_{уч} + Z,$$

R – is the specific pressure losses on friction, Pa/m. Z – is pressure losses on local resistances, Pa.

Loss of pressure in the circulating ring of the system with sequential connection of N sections:

$$\Delta p_{общ} = \sum_{i=1}^{N} (R l_{уч} + Z)_i,$$

with parallel connection of two sections, risers or branches: $\Delta p_i = \Delta p_j,$

2. Using characteristics of resistance and conduction.

$$\begin{aligned} \Delta p_{уч} &= ((\lambda / d_в) l_{уч} + \sum\zeta_{уч})(\rho w_{уч}^2 / 2) = \\ &= (A_{уч}((\lambda / d_в) l_{уч} + \sum\zeta_{уч})) G_{уч}^2 = \\ &= S_{уч} G_{уч}^2, \end{aligned}$$

where $w_{уч} = 4G_{уч} / (3600\rho\pi d_в^2)$ - water velocity, m / s; $G_{уч}$ - water flow in the calculated section, kg / h; $A_{уч}$ is the specific hydrodynamic pressure in the section, Pa / (kg / h)^2, which occurs when the water flow is 1 kg / h, which is calculated by the formula.

$$A_{уч} = 6{,}25 / (10^8 \rho d_в^4);$$

Sуч is the characteristic of the hydraulic resistance of the section, Pa / (kg / h)^2, expressing the pressure loss at the section at a single flow rate of water (1 kg / h):

$$S_{уч} = A_{уч}((\lambda / d_в) l_{уч} + \sum \zeta_{уч}).$$

Loss of pressure on the section can be found using the conduction of the section:

$$\Delta p_{уч} = (G_{уч} / \sigma_{уч})^2,$$

where σуч is the conductivity of the section, kg / (h · Pa$^{0.5}$), showing the water flow at a single loss of pressure in the section (1 Pa).

Conductivity is related to the characteristic of resistance by the dependence $\sigma = 1 / S^{0{,}5}$.

Hydraulic calculation of water heating system using specific linear pressure loss

The calculation begins with **the main circulation ring** of the system.

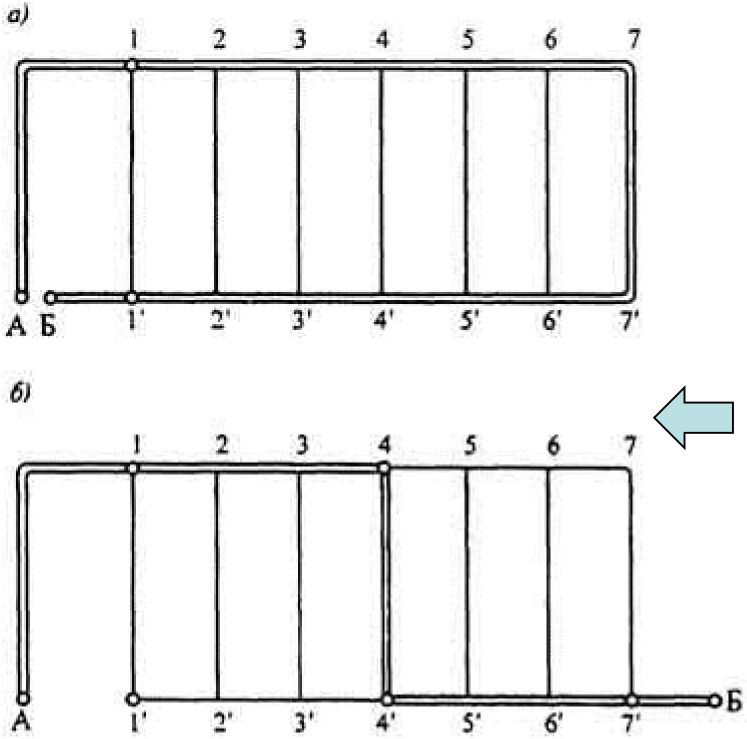
The main circulation ring is the ring in which the calculated circulating pressure Δp_p per unit length of the ring Σl has the smallest value: $\Delta p_l = \Delta p_p / \sum l = \min.$

For a vertical one-pipe system it is the ring through the most loaded riser from the risers laying long away from the heat point.
For a vertical two-pipe system, this is a ring through the lower heating device of the most loaded riser from the heat point.
For a horizontal one-pipe system of a multi-storey building, the main circulating ring is selected for a smaller value of Δpl in two circulation rings through branches on the upper and lower floors.

When choosing the diameter of the pipes in the circulation ring, proceed from the accepted water flow and the average value of the specific linear pressure loss Rcp, Pa/m (assuming a pressure loss of friction equal to 65% Δp_p):

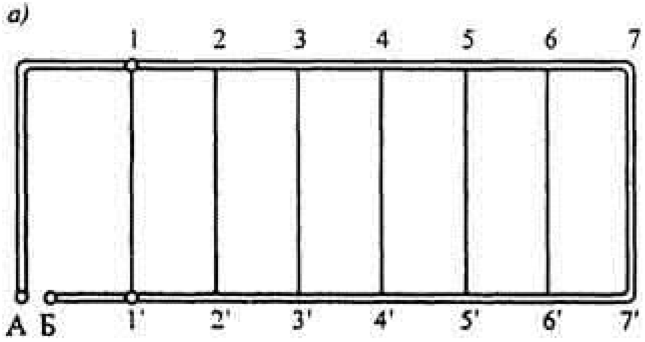
$$R_{cp} = 0{,}65 \Delta p_p / \sum l,$$

Where Σl is the total length of of serially connected sections constituting the main circulation ring, m.



Calculated schemes of circulating rings of vertical heating systems:
a –when water in flow and return lines moves in different directions;
b – when water in flow and return lines moves in the same direction

Hydraulic calculation of circulating rings with water movement in flow and return lines in different directions (variant a)



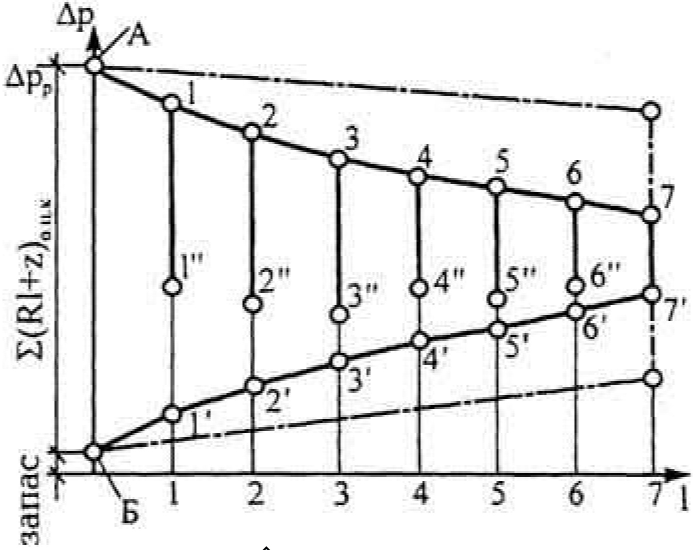


Diagram of circulating pressure in the heating system: 1-7 - points of connection of risers to the main lines.

Secondary circulation rings consist of common sections of the main ring (already calculated) and additional (not common) sections not yet calculated.

They are calculated with "linking" of the pressure losses.

Linking means that we need to obtain the equality of pressure losses in connected in parallel way additional sections of the secondary ring and not common sections of the main ring.

$$\sum(Rl + Z)_{ст} = \Delta p_{р.ст},$$

where $\Delta p_{р\ ст}$ is the available circulation pressure obtained as a result of calculation of the main circulating ring.

Therefore, the available circulating pressure $\Delta p_{р\ ст}$ should be equal to the pressure loss (already known) at the sections of the main ring closing the considered riser. Thus, for a two-pipe system:

$$\Delta p_{р.ст} = \sum(Rl + Z)_{осн};$$

for an one-pipe system:

$$\Delta p_{р.ст} = \sum(Rl + Z)_{осн} + (\Delta p_{е.вт} - \Delta p_{е.осн}),$$

here we take into account the correction to the natural circulating pressure in the secondary $\Delta p_{е.ВТ}$ and main rings $\Delta p_{е.ОСН}$.

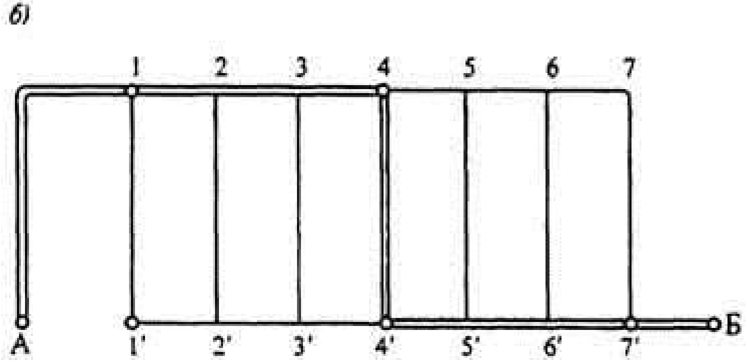
For example for riser 1: $\Delta p_{р.ст..1} = \sum(Rl + Z)_{1\text{-}7\text{-}7'\text{-}1'}.$

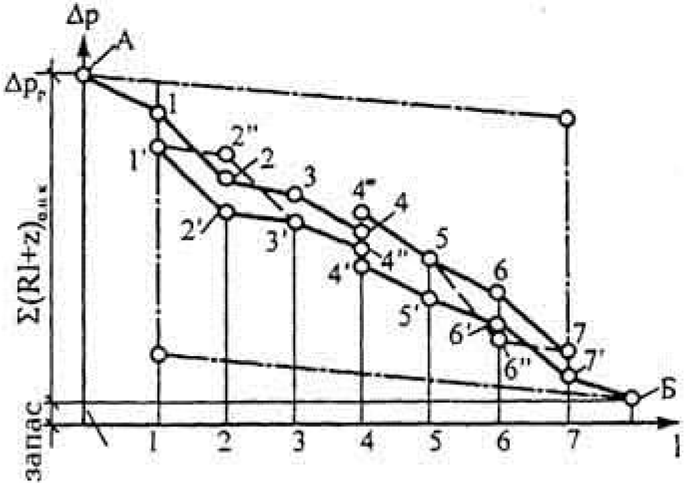
For the case with water movement in different directions in main lines, "linking" can equal to up to 15%.

Diameter of throttling diaphragm: $d_д = 3{,}5(G_{ст}^2 / \Delta p_д)^{0{,}25}$,

where $G_{ст}$ is calculated water flow in riser, kg / h; $\Delta p_д$ is the excess pressure, which must be absorbed by the diaphragm, Pa (for example, for riser 1).

Hydraulic calculation of circulating rings with water movement in flow and return lines in one direction (variant b)





For example, to calculate the additional sections belonging to the secondary circulation ring through the riser 1:

$$\Delta p_{р.ст.1} = \sum(Rl + Z)_{1\text{-}4\text{-}4'},$$

through the riser 7: $\Delta p_{р.ст.7} = \sum(Rl + Z)_{4\text{-}4'\text{-}7'}.$

For the case with water movement in one direction in main lines, “linking” can equal to up to 5%.

Example of hydraulic calculation

To calculate the main circulation ring of pump (with elevator) two-pipe water heating system with lower laying of the main lines and water movement in different directions in main lines. tг=95 °C, to=70 °C. Heating devices are steel panel radiators RSG-2, located under windows.
The pump circulation pressure transmitted to the system through the elevator is Δpн = 10 kPa.
The main circulating ring – is chosen through the heater on the 1st floor in the 7 riser.

Calculated circulation pressure using:

$\Delta p_p = \Delta p_н + 0{,}4\Delta p_e.\ \ \Delta p_{e.пр.1} = gh_1(\rho_o - \rho_г),$ where ρo - ρг = β(tг -t0), β=0,64 kg/(m3·°C) (Ref. liter.)

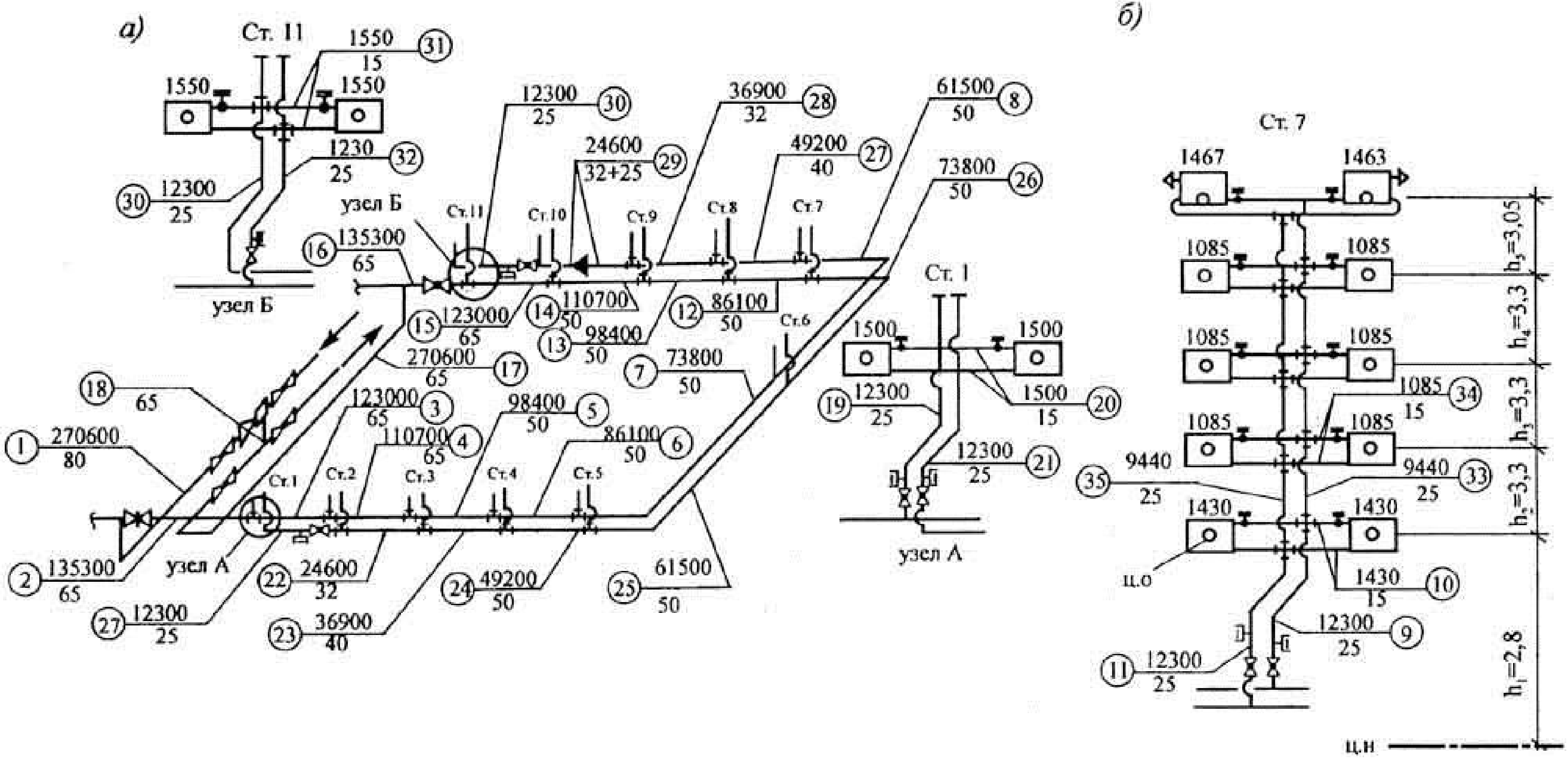
$$\Delta p_p = 10000+0{,}4\cdot 0{,}64\cdot 9{,}81\cdot 2{,}8(95 - 70) = 10176\ Па.$$

Average specific linear pressure losses: $R_{cp} = 0{,}65\Delta p_p / \Sigma l,$

$$R_{cp} = 0{,}65\cdot 10176 / 123{,}7 = 53{,}5\ Па/м.$$

Water flow rate for each section $G_{уч} = Q_{уч}\beta_1\beta_2 / (c(t_г - t_o)),$

According to flow rates, choose pipe diameter Dy. Using Rcp choose R (linear pressure losses)


а)
б)
Ст. 11
узел Б
узел А
Ст. 1
Ст. 7
Ст.1
Ст.2
Ст.3
Ст.4
Ст.5
Ст.6
Ст.7
Ст.8
Ст.9
Ст.10
Ст.11
ц.о
ц.н
$h_1=2,8$
$h_2=3,3$
$h_3=3,3$
$h_4=3,3$
$h_5=3,05$

Данные по участкам схемы				Принято						
№	Q, Вт	G, кг/ч	l, м	D_y, мм	w, м/с	R, Па/м	Rl, Па	$\sum\zeta$	Z, Па	Rl + Z, Па
1	270600	10800	9,0	80	0,56	48	432	0,8	123	555
2	135300	5400	8,0	65	0,39	30	240	6,8	506	746
3	123000	4920	8,0	65	0,355	25	200	0,2	12	212
4	110700	4430	8,0	65	0,32	21	168	0,2	10	178
5	98400	3930	8,0	50	0,52	78	624	0,2	26	650
6	86100	3450	6,0	50	0,46	60	360	0,2	21	381
7	73800	2950	12,0	50	0,39	45	540	0,5	37	577
8	61500	2460	12,0	50	0,33	31	372	0,5	27	399
9	12300	493	1,8	25	0,24	42	76	8,4	236	312
10	1430	57	3,0	15	0,083	12	36	28,1	95	131
11	12300	493	1,4	25	0,24	42	59	3,4	96	155
12	86100	3450	6,0	50	0,46	60	360	0,7	72	432
13	98400	3930	8,0	50	0,52	78	624	0,7	93	717
14	110700	4430	8,0	50	0,59	98	784	0,7	119	903
15	123000	4920	8,0	65	0,355	25	200	0,5	31	231
16	135300	5400	4,0	65	0,39	30	120	5,5	408	528
17	270600	10800	12,0	(80)	(0,56)	(48)	(576)	(1,4)	(214)	(790)
				65	0,78	116	1392	1,4	416	1808
18	-	7425	0,5	65	0,54	56	28	1,5	213	241
		$\sum l$ = 123,7							$\sum$ (Rl + Z) = (8138) 9156	

Calculate velocity of water movement: w=G/(Fρ). → Table

Calculate linking:

$$((\Delta p_p - \Sigma(Rl + Z)) / \Delta p_p)100 = ((10176 - 8138) / 10176)100 = 20\ \%.$$

data from table

“Linking” is higher than 10%. If we decrease the diameter of 17 section, pressure losses increases for this section and we obtain:

$$((10176 - 9156) / 10176)\cdot 100 = 10\ \%.$$

The sum of local resistance coefficients:

Cross-section on the branch at flow division at:

$d_{отв} = 15/25 = 0{,}59$, $G_{отв} = 57/492 = 0{,}11$ |8$G_{отв} = G_{отв}$,.....15.3

Double adjustment valve Dy15 ..14,0

radiator RSG-2 with Du15 .... 1.2

Cross on the branch at the confluence (слияние) of flows at $d_{ОТВ}$ = 0.59 and $G_{ОТВ}$ = 0.11…..2.4

$$\Sigma\zeta_{10} = 28.1$$

As a result of the calculation, in order to obtain equality, it was necessary to reduce the diameter of section 17, since a stock of circulating pressure (20%) considerably exceeded the required pressure of 5 ... 10%.

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