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INDUSTRIAL PLANTS

Chapter twenty-eight:

Piping – Fluid distribution plants – Design of distribution networks

DOUBLE DEGREE MASTER IN

“PRODUCTION ENGINEERING AND MANAGEMENT”

SEAT OF PORDENONE

UNIVERSITY OF TRIESTE

Design of distribution networks

Generality

The **design of the distribution networks of industrial water and drinking water** in industrial plants consists in the determination of the diameters of the pipes, since they are generally known their lengths of the lines, the pressures and flow rates of water required by the loads.

The lengths are known as it is established the **geometry of the network**, depending on the plant layout, to the characteristics of the building, to the needs of the service etc. The **flow of water to be supplied to the users**, are another given of the problem together with the pressure required by the use.

An ***evaluation of large maximum of the diameter of the pipes*** is already known for a certain flow conveyed as it can take the average values of the fluid velocity ranging between 1 and 2 m/s.

Design of distribution networks

Generality

The **fire-fighting water network**, since it is used occasionally and for limited times, is not determined by the criterion of minimum cost; therefore this network is dimensioned assuming values of the water velocity variable between 2 and 3 m/s. It provides a external fire network the plant (above ground) and an inner (overhead), usually these networks are at ring with cross connections in the case of internal networks. Networks both internal and ground are made with the same types of pipes, valves and fittings of industrial water networks.

The **project** is executed by knowing the pressures of the pressure losses along the circuit, due to friction (distributed losses) and in the presence of accidentality (localized losses in the deviations, valves, section changes, etc.).

Design of distribution networks

Generality

The literature provides some diagrams that allow to highlight the relationship between pressure drop, diameter, flow rate and velocity of the water in the case of straight tubes made of steel, plastic, etc.

The expression of the **losses distributed** J (bar) can be of the form:

$$J = \rho \cdot g \cdot \frac{L}{d} \cdot \lambda \cdot \frac{v^2}{2} = \rho \cdot g \cdot \frac{L}{d} \cdot \lambda \cdot \frac{8 \cdot Q^2}{\pi \cdot d^4}$$

where:

ρ = density of the fluid (kg/m^3);

g = acceleration of gravity (m/s^2),

L = length of pipe (m);

d = inner diameter of the pipe (m);

v = fluid velocity (m/s)

Q = fluid flow rate (m^3/s);

Design of distribution networks

<u>Generality</u>

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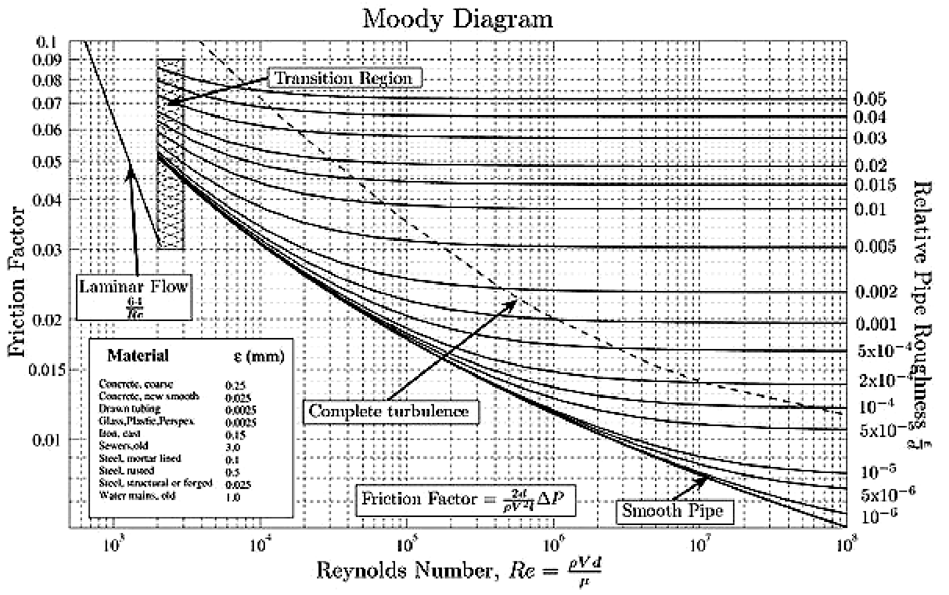
where:

λ = coefficient of friction, which can be derived for the various types of roughness of the pipe from the Moody diagram as a function of the Reynolds number Re;

$$Re = \frac{\rho \cdot v \cdot d}{\mu}$$



μ= dynamic viscosity of the fluid (Pa s) that defines the cohesion of the fluid.

Design of distribution networks

<u>Generality</u>

Normally, the manufacturer provides tables that showing the values of pressure drop in m/km, which vary depending on the materials, the type of processing and treatments that are performed on the pipes. These values are obtained from specific formulas which can be easily found in the literature.

Below is reported as an example the case of the calculation of the loss of load (m/km of pipe) of steel pipes, bituminous internally, having diameters ranging from DN 40 to DN 400 and piping water at 15°C, for which using the formula Scimemi-Veronese:

$$J = 6{,}81 \cdot 10^8 \cdot \frac{Q^{1{,}82}}{d^{4{,}71}}$$

having expressed the water flow in dm^3/s and the pipe diameter in mm.

Generality

To take into account that, with **time**, the load losses in the pipes increases, it is advisable to multiply the values of J by a coefficient comprised between 1.1 (water little hard, non-aggressive and having low acidity or for pipes having diameters more high of the range considered) and 1.4.

In general, these calculations are not made directly by the designer, but as mentioned are provided and cataloged by the manufacturer. In case you want to calculate the values of pressure drop for a generic pipeline without knowing the characteristic equation, the equation used is that of Darcy, equality on which they are based, inter alia, some of the equations relate to piping details.

Generality

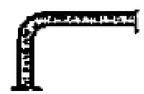
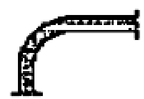
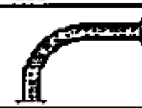
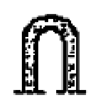
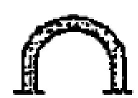
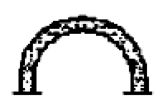
For **localized pressure losses**, the calculations are based on the coefficient of loss of load localized ξ, which represents the sum of all localized losses of the pipe considered (valves, gate valves, bends, T, variations in section etc.).

The measurement of the pressure drop (bar) is expressed by the relation:

$$\Delta p = \sum_{i=1}^{n} \zeta \cdot \frac{v^2}{2 \cdot 10^5} \cdot \rho$$

Generality

The coefficient ξ is tabulated as a function of the accidental.

Internal diameter copper tubes, PEad, PEX		8÷16 mm	18÷28 mm	30÷54 mm	>54 mm
Outside diameter of steel pipes		3/8"÷1/2"	3/4"÷1"	1 1/4"÷2"	>2"
Type of localized resistance	Symbol				
Curve grasp to 90° r/d = 1,5		2,0	1,5	1,0	0,8
Curve normal to 90° r/d = 2,5		1,5	1,0	0,5	0,4
Curve large to 90° r/d > 3,5		1,0	0,5	0,3	0,3
Curve grasp to U r/d = 1,5		2,5	2,0	1,5	1,0
Curve normal to U r/d = 2,5		2,0	1,5	0,8	0,5
Curve large to U r/d > 3,5		1,5	0,8	0,4	0,4

Generality

To take account of losses in the joints, it is recommended to store an additional margin of 10-15%, in order to take into account the quality of the pipe, for which the roughness tends to increase, and the number and quality of the joints. The coefficients of loss of load localized individual depend on the nominal diameter of the pipes and by their shape, and may also be expressed in terms of equivalent length:

$$\zeta = \frac{\lambda \cdot L_{eq}}{d}$$

converting them into equivalent distributed losses, and simplifying somewhat the calculations.

Generality

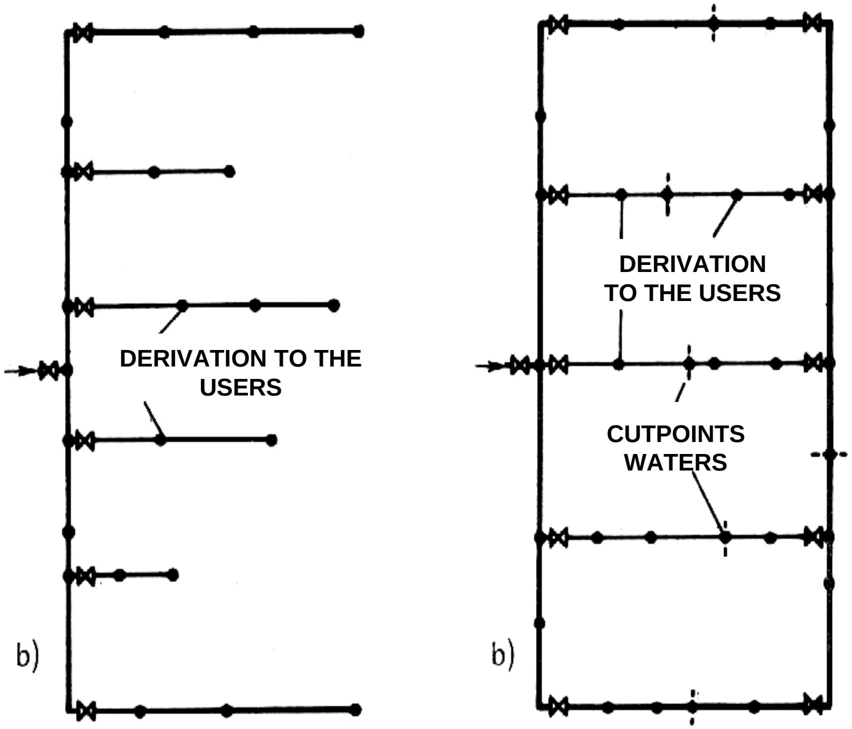
Numerous tables and graphs provide the equivalent pipe length or the loss of load due to valves, gate valves, bends, T, variations in section etc.

DN	Curve			Fittings		Gate valve	Check valve
	45°	90°	90° large radius	T	Cross		
	Equivalent pipeline length (m)						
25	0,3	0,6	0,6	1,5	1,5	-	1,5
32	0,3	0,9	0,6	1,8	1,8	-	2,1
40	0,6	1,2	0,6	2,4	2,4	-	2,7
50	0,6	1,5	0,9	3,0	3,0	0,3	3,3
65	0,9	1,8	1,2	3,6	3,6	0,3	4,2
80	0,9	2,1	1,5	4,5	4,5	0,3	4,8
100	1,2	3,0	1,8	6,0	6,0	0,6	6,6
125	1,5	3,6	2,4	7,5	7,5	0,6	8,3
150	2,1	4,2	2,7	9,0	9,0	0,9	10,4
200	2,7	5,4	3,9	10,5	10,5	1,2	13,5
250	3,3	6,6	4,8	15,0	15,0	1,5	16,5
300	3,9	8,1	5,4	18,0	18,0	1,8	19,5

Generality

There are two types of network used for water distribution and for which it will carry out the design:

- networks to comb;
- networks to mesh.



Design of distribution networks

Design of distribution networks to comb

The **design of distribution networks** is carried out starting from the known data of the project, which are the lengths of the individual sections of the pipes, the flow rates and pressures required by the loads.

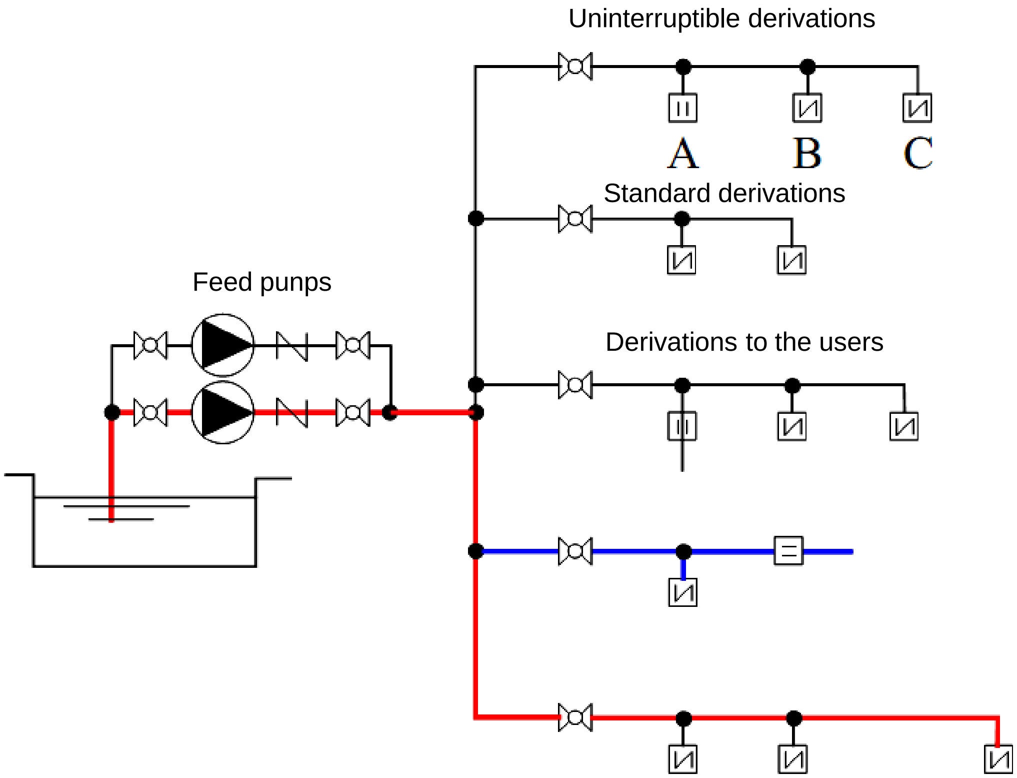
When you are faced with a network to comb is always necessary to define the **main branch** (or **main manifold**), that is, that set of trunks in series (the pipe portions paths the same scope and having only one diameter), which joins the source of supply to users worst off.

Since the diameters of the logs have not yet been defined, the identification of the main collector will be based on the first two of the variables (total pressure request and the distance), while the pressure drop will be taken into account on the basis of experience, unless subsequent verification.

Design of distribution networks

Design of distribution networks to comb

As a first attempt, you can use graphs or tables that provide the loss of load distribution as a function of the nominal diameter and the flow rate of water flowing.



Design of distribution networks

Design of distribution networks to comb

He then proceeds:

- sizing the various trunks of the main collector;
- calculating the energy possessed by the fluid at the nodes of branch belonging to the manifold;
- sizing the secondary branches, so that they result balanced with the main collector. In this case, the water that arrives to a branch must have the same energy loss in passing through the rest of the main collector and the trunk branch, to their respective local flow rates. You need to obtain this result through the appropriate choice of the diameters of individual trunks, perhaps with the aid of the insertion of adjusting devices or choking in the secondary trunks.

Design of distribution networks

Design of distribution networks to comb

The relative sizing to the branch of the main collector can be conducted according to various criteria:

- setting, for each trunk, a speed between 1 and 2 m/s;
- setting, for each trunk, the same pressure drop specification (attached table);
- determining the diameters of logs belonging to the main collector, using the criterion of minimum total cost.

Design of distribution networks

<u>Design of distribution networks to comb</u>

Pressure drop
for each trunk

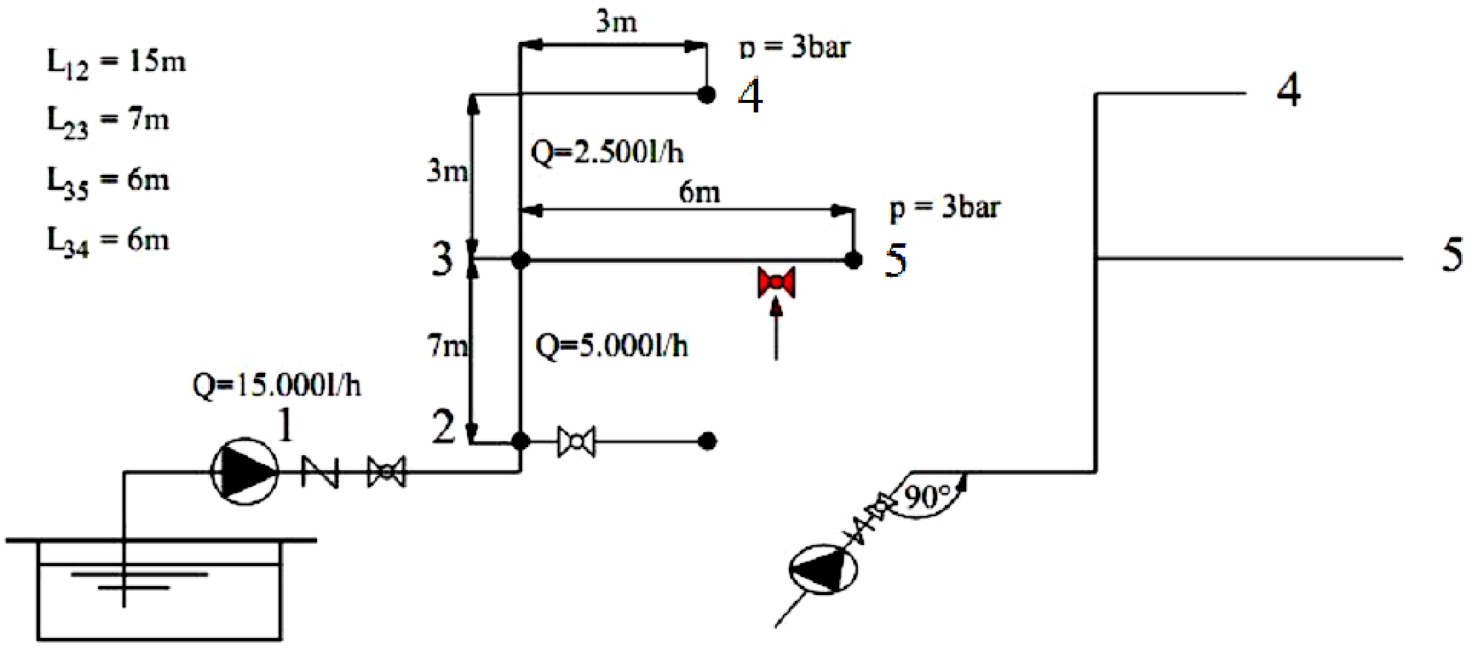
Q [dm³/s]		v [m/s]				Δpc [mc.a/km]									
	DN	**50**	**60**	**80**	**100**	**125**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**600**
	$Ø_{int}$	53.9	69.7	81.7	106.3	130.7	159.3	208	260	310	341	390	441	490	590
1	v	0.44	0.26	0.19											
	Δpc	6.19	1.77	0.82											
2	v	0.88	0.52	0.38	0.23										
	Δpc	22.33	6.39	2.95	0.82										
4	v	1.75	1.05	0.76	0.46	0.30	0.20								
	Δpc	80.51	23.02	10.62	2.96	1.06	0.41								
6	v	2.63	1.57	1.15	0.68	0.45	0.30	0.18							
	Δpc	170.45	48.74	22.49	6.24	2.28	0.87	0.24							
8	v	3.61	2.10	1.53	0.90	0.60	0.40	0.24							
	Δpc	260.22	82.99	36.29	10.63	3.58	1.48	0.41							
10	v	4.39	2.62	1.91	1.13	0.75	0.50	0.29	0.19						
	Δpc	438.54	125.40	57.85	16.06	6.87	2.24	0.61	0.20						
12	v		3.15	2.29	1.35	0.90	0.60	0.35	0.23						
	Δpc		175.71	81.06	22.50	8.22	3.14	0.86	0.29						
15	v		3.94	2.86	1.69	1.12	0.75	0.44	0.28	0.20					
	Δpc		265.61	122.49	33.99	12.48	4.74	1.30	0.43	0.19					
20	v		5.25	3.82	2.28	1.49	1.00	0.59	0.38	0.27	0.22				
	Δpc		452.08	208.56	57.88	21.16	8.07	2.21	0.74	0.32	0.20				
25	v			4.77	2.82	1.87	1.26	0.74	0.47	0.33	0.27	0.21			
	Δpc			315.15	87.48	31.97	12.20	3.33	1.11	0.48	0.30	0.16			
30	v			5.73	3.38	2.24	1.51	0.88	0.56	0.40	0.33	0.25	0.20		
	Δpc			441.57	122.56	44.80	17.09	4.67	1.56	0.67	0.42	0.22	0.12		
35	v			6.68	3.95	2.61	1.76	1.03	0.66	0.47	0.38	0.29	0.23	0.19	
	Δpc			587.29	162.99	59.58	22.73	8.21	2.08	0.89	0.56	0.29	0.16	0.10	
40	v				4.51	2.98	2.01	1.18	0.75	0.53	0.44	0.33	0.26	0.21	
	Δpc				208.66	76.28	29.10	7.96	2.66	1.14	0.71	0.37	0.20	0.12	
45	v				5.08	3.36	2.26	1.33	0.85	0.60	0.49	0.38	0.29	0.24	
	Δpc				259.46	94.85	30.18	9.89	3.80	1.42	0.88	0.46	0.25	0.19	
50	v				5.64	3.73	2.51	1.47	0.94	0.66	0.56	0.42	0.33	0.26	0.18
	Δpc				315.30	115.26	43.97	12.02	4.02	1.73	1.07	0.58	0.31	0.18	0.08
60	v				6.77	4.48	3.01	1.77	1.13	0.80	0.66	0.50	0.39	0.32	0.22
	Δpc				441.79	161.50	61.61	16.85	5.63	2.42	1.50	0.78	0.43	0.26	0.11
70	v				7.90	6.22	3.52	2.05	1.32	0.93	0.77	0.59	0.46	0.37	0.26
	Δpc				587.58	214.79	81.94	22.40	7.46	3.22	2.00	1.04	0.57	0.34	0.14
80	v					5.97	4.02	2.36	1.50	1.06	0.87	0.67	0.52	0.42	0.29
	Δpc					274.98	104.90	28.68	9.58	4.12	2.56	1.33	0.73	0.44	0.16
90	v					6.71	4.52	2.65	1.69	1.20	0.96	0.75	0.59	0.48	0.33
	Δpc					341.93	130.44	35.67	11.91	5.12	3.19	1.66	0.91	0.65	0.22
100	v					7.45	6.02	2.95	1.88	1.33	1.09	0.84	0.65	0.53	0.37
	Δpc					416.52	156.51	43.34	14.45	6.22	3.87	2.01	1.11	0.66	0.27
125	v					9.33	6.28	3.69	2.35	1.66	1.37	1.05	0.82	0.66	0.46
	Δpc					827.87	239.52	65.48	21.88	9.40	6.86	3.04	1.68	1.00	0.41
150	v						7.63	4.42	2.82	1.99	1.64	1.26	0.98	0.79	0.65
	Δpc						335.60	91.76	30.65	13.17	8.20	4.27	2.35	1.40	0.57
200	v						10.04	5.90	3.76	2.66	2.19	1.67	1.31	1.06	0.73
	Δpc						571.43	166.24	52.19	22.43	13.96	7.26	4.00	2.39	0.98
250	v							7.37	4.70	3.32	2.73	2.09	1.64	1.32	0.92
	Δpc							236.10	78.86	38.90	21.09	10.87	6.05	3.61	1.47
300	v							8.75	5.64	3.99	3.28	2.51	1.96	1.59	1.10
	Δpc							330.81	110.50	47.49	29.55	15.38	8.48	5.06	2.06
350	v							10.32	6.68	4.85	3.83	2.93	2.29	1.85	1.28
	Δpc							439.97	146.96	63.17	39.30	20.45	11.27	6.74	2.75
400	v							11.79	7.62	5.32	4.37	3.34	2.62	2.12	1.47
	Δpc							563.26	188.14	80.87	60.31	26.18	14.43	8.62	3.62
450	v								8.46	5.98	4.92	3.76	2.95	2.38	1.65
	Δpc								233.95	100.56	62.56	32.56	17.94	10.72	4.37
500	v								9.40	6.54	5.47	4.18	3.27	2.65	1.83
	Δpc								284.30	122.20	76.02	39.56	21.81	13.03	5.31

Design of distribution networks

Design of distribution networks to comb

In any case it must be borne in mind that in the choice of the criterion is important to the use and the size of the plant.

The network of figure, whose data show that industrial activity is positioned on two levels. As a first attempt, it identifies the main manifold as the one that passes between the points 1, 2, 3 and 5.



Design of distribution networks to comb

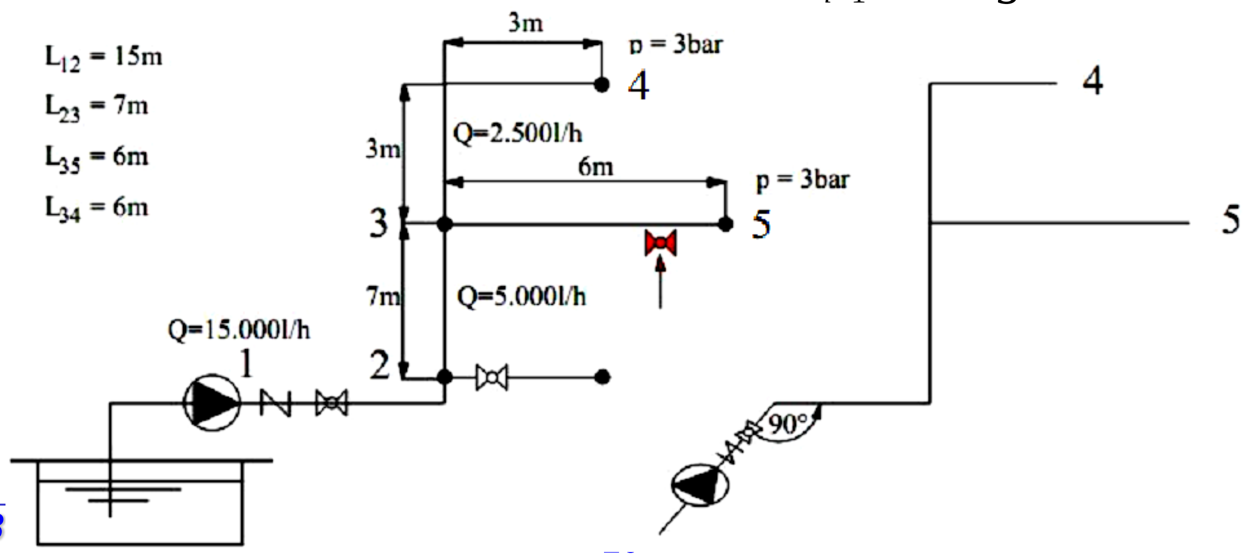
In table lists the accidentality, with the respective coefficients of localized loss.

Tronco	Q (dm^3/s)	DN (mm)	v (m/s)	R (mm C.A./m)	L (m)	R_d (mm C.A.)	$\Sigma\zeta_d$	$v^2/2g\cdot10^3$ (mm C.A.)	R_A (mm C.A.)	R_{tot} (mm C.A.)	Δz (mm C.A.)	Δp (mm C.A.)
1-2	4,17	60	1,82	55	15	825	0,3					
							2					
							0,5	168,8	500,6	1325,6	0	1325,6
2-3	1,39	42	1,31	55	7	385	1					
							0,5	87,5	131,2	169,7	3000	3169,7
3-5	0,69	33,5	1,01	55	6	330	1					
							0,5					
							0,5	52,0	104,0	434,0	3000	3434,0
TOTALE (mm C.A.)												7929,3

Design of distribution networks to comb

The user 4 is located at a height of 3 m geodetic respect to the section 3-5 and requires a pressure of 3 bar. So, for the power user 4, it is necessary to ensure the pressure drop of the trunk 3-5, equal to 3169.7 mm C.A., so that the network is balanced here. The secondary branch 3-5 is affected by the water flow rate of 2,500 l/h = 0.69 m^3/s, and should satisfy the relation:

$$\Delta p_{3-4} = p_3 - p_4 = 3434{,}0 = R_d \cdot L = \sum_{i=1}^{3} \zeta \cdot \frac{v^2}{2 \cdot g} \cdot 10^3$$



Design of distribution networks to comb

Choosing a DN with inner diameter 21.5 mm, which presents a distributed loss of 200 mm C.A./m, the velocity of the water is:

$$v = \frac{Q}{A} = \frac{2500}{3600 \cdot 1000} \cdot \frac{4}{\pi \cdot 0{,}0215^2} = 1{,}91\ m/s$$

and the loss of load localized ξ = 2 for the passage through two 90° elbows, is:

$$R_A^{'} = 2 \cdot \frac{v^2}{2 \cdot g} \cdot 1000 = 279\ mm\, C.A.$$

$$R_d^{'} = 200 \cdot 6 = 1200\ mm\, C.A.$$

$$\Delta p_{3-4} = R_A^{'} + R_d^{'} = 1479\ mm\, C.A.$$

Design of distribution networks to comb

Since the actual pressure to the user 4 is greater than required, it can act by decreasing the DN below what was chosen, or increasing the loss of load localized, by entering, for example, a regulating valve. On the other hand, the reduction of DN to an internal diameter of 17.2 mm would result in an excessive velocity of the water (equal to 3 m/s). Ultimately, the pipe has the correct diameter for the speed of the water and it is necessary to insert a valve.

For the design of distribution networks comb you can use the **method of economic diameter**.

Since the diameter of the pipe is cheaper than that for which the first derivative of C with respect to D is canceled, highlighting L/D_{n+1}, it follows that the condition of minimum cost is one for which:

$$m \cdot r_1 \cdot A \cdot D^{m-n} = n \cdot r_2 \cdot B \cdot p \cdot \beta \cdot Q^3 \cdot \left(\frac{9{,}8}{\eta}\right)^p \cdot \left(Q \cdot H + \frac{Q^3}{D^n} \cdot L\right)^{p+1} + n \cdot c_w \cdot N \cdot \frac{9{,}81}{\eta} \cdot \beta \cdot Q^3$$

Design of distribution networks

Design of distribution networks to comb

Introducing the flow of water to be pumped and the diameters of the tubes unified, resolves the above equation. If you fall between two commercial values, select diameter for which dC/dD is the absolute value lower.

Design of distribution networks to mesh

For the design of this type of distribution network may be employed various methods each of which implies certain underlying assumptions and calculation procedures distinct. This discussion will present the three methods known and used: the **method of maximum economy**, the **parametric method** and the **method of Cross** (or load balancing).

Design of distribution networks to mesh

The **method of maximum economy** is based on the simplified assumption that the cost of piping is proportional to the diameter.

Must satisfy the relations:

a) ***equation of continuity of flow applied to the node of the network***

$$\sum_N \left(\pm q_i\right) \pm Q_N = 0$$

b) ***principle of continuity of loads or equations of motion applied to each mesh of network***

$$\sum_N \left(\pm h_i\right) = 0$$

The determination of the diameters and piezometric shares may be carried out with the ***equation of maximum economy***

$$\sum_N \left(\pm \frac{D_i \cdot l_i}{h_i}\right) = 0$$

Design of distribution networks to mesh

Assumed that the cost is proportional to the diameter of the piping, the cost of the 3 branches is expressible with the report:

$$C = R \cdot (D_1 \cdot l_1 + D_2 \cdot l_2 + D_3 \cdot l_3)$$

from which we must look for the lowest cost, with the first derivative with respect to Z of the total cost:

$$\frac{dC}{dZ} = 0$$

where:

$$D_1 = \left(\frac{\beta \cdot q_1^2 \cdot l_1}{Z_1 - Z} \right) \qquad D_2 = \left(\frac{\beta \cdot q_2^2 \cdot l_2}{Z_2 - Z} \right) \qquad D_3 = \left(\frac{\beta \cdot q_3^2 \cdot l_3}{Z_3 - Z} \right)$$

Design of distribution networks to mesh

The **parametric method** does not introduce more the hypothesis that the cost of the piping is directly proportional to the diameter.

The starting data are the knowledge of the geometry of the circuit, the flow rates to the users and of the values of the minimum pressure to ensure at the same.

The process is iterative.

Design of distribution networks

Design of distribution networks to mesh

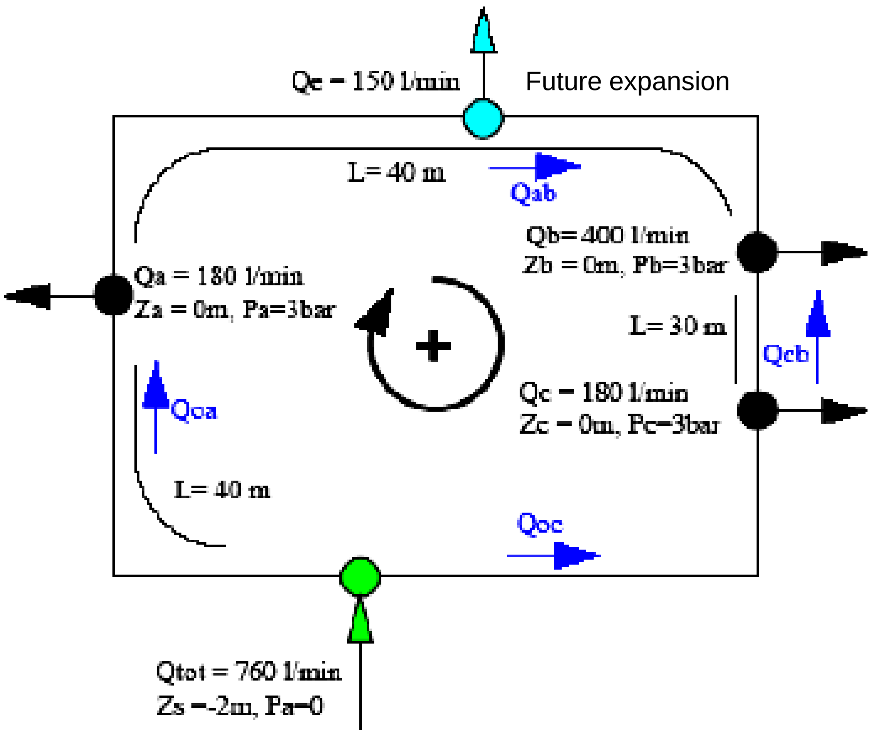
The **method of Cross** or **load balance** that satisfies the equation of continuity of flow.

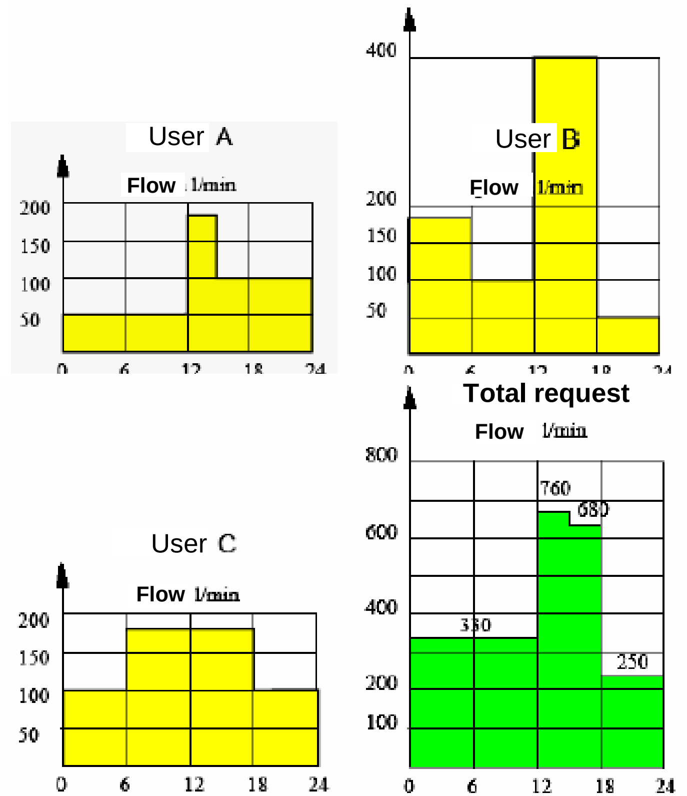
$$\sum_{N}\left(\pm q_i\right)\pm Q_N = 0$$

This solution will be unbalanced with respect to the loads; must therefore be corrected, by circulating in each mesh a flow rate such as to achieve load balancing.

Design of distribution networks to mesh

Suppose we wish to size the closed network on a single layer (Figure), in which there are 3 loads, whose diagram of consumption is that of figure. A fourth user is provided as a later development. The mesh is laid pipe DN 70.

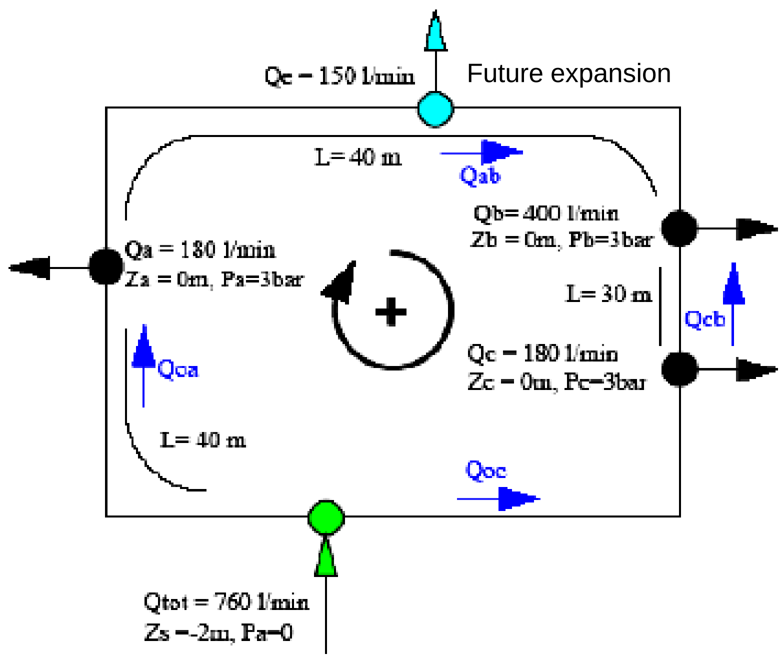




Design of distribution networks to mesh

The centrifugal pump at the service of the network will be chosen according to the performance demands of users, all of which require a pressure of 3 bar. As can be seen from the diagrams of requests, at the top right, the critical period occurs from the 12.00 to the 15.00 hours, and, in a first phase, represents the design data of the network.

As you can see in the figure, we have chosen a direction of travel of the mesh (time) and an arbitrary direction of flow in the branches.



Design of distribution networks to mesh

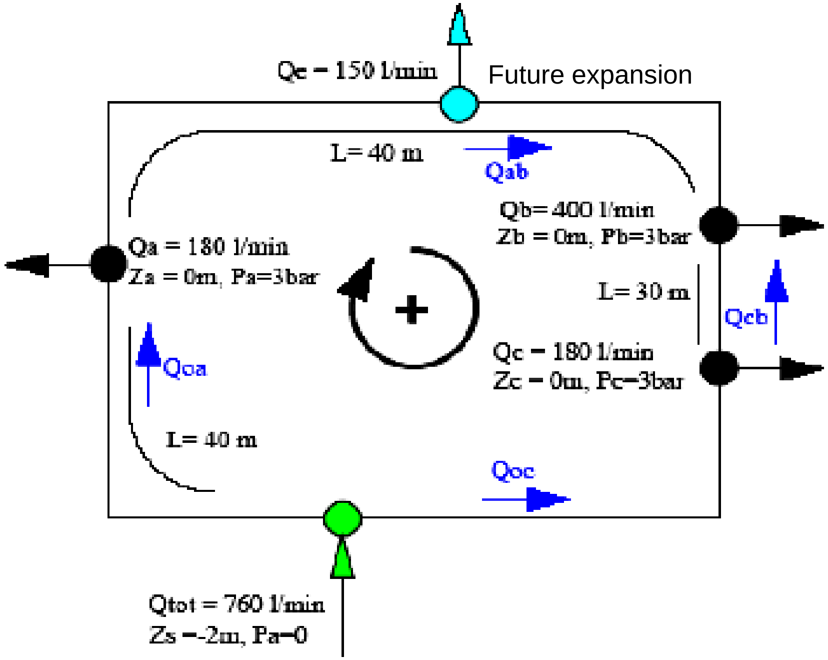
The equations of equilibrium of the flow rates to the nodes are (values of the flow in l/min):

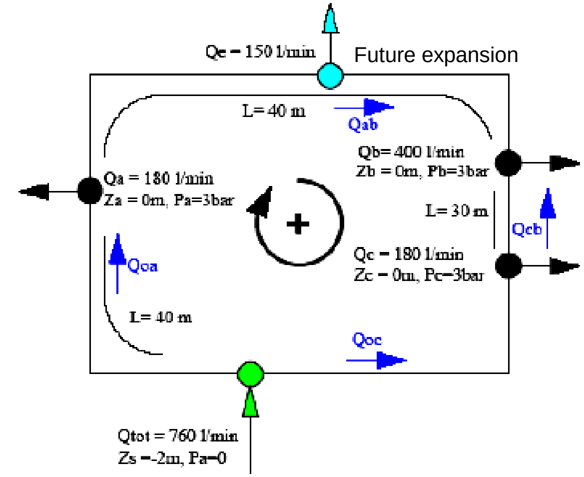
equation node o $Q_{oa} + Q_{oc} = Q_1 = 760$

equation node a $Q_{oa} = Q_{ab} + Q_a = Q_{ab} + 180$

equation node b $Q_{ab} = Q_b - Q_{cb} = 400 - Q_{cb}$

equation node c $Q_{oc} = Q_{cb} + Q_c = Q_{cb} + 180$





Design of distribution networks

Design of distribution networks to mesh

The equilibrium equations of the mesh are:

$$\Delta p_{oa} + \Delta p_{ab} + \Delta p_{cb} + \Delta p_{oc} = 0$$

The arbitrary solution that satisfies the equation of equilibrium to the nodes is: $Q'_{oa} = 180 \ l/\min$ $\quad Q'_{ab} = 0 \ l/\min$ $\quad Q'_{cb} = 400 \ l/\min$ $\quad Q'_{oc} = 580 \ l/\min$

The flow rates corrective, which present the sign in accordance with the direction of the currents, are:

$$\Delta Q = -\frac{\sum_N k_i \cdot f(q_i)}{\sum_N k_i \cdot f'(q_i)} = -\frac{Q_{oa}^2 \cdot L_{oa} + Q_{ab}^2 \cdot L_{ab} - Q_{cb}^2 \cdot L_{cb} - Q_{oc}^2 \cdot L_{oc}}{2 \cdot \left(Q_{oa} \cdot L_{oa} + Q_{ab} \cdot L_{ab} + Q_{bc} \cdot L_{bc} + Q_{oc} \cdot L_{oc}\right)} = 155$$

The first correct solution is the following:

$Q''_{oa} = 335 \ l/\min$ $\quad Q''_{ab} = 155 \ l/\min$ $\quad Q''_{cb} = 245 \ l/\min$ $\quad Q''_{oc} = 425 \ l/\min$

that, since ΔQ added clockwise to all the branches, does not alter the equilibrium equations of the flow to the nodes

Design of distribution networks to mesh

It then performs the calculation of the balance of the pressure drops in the mesh:

$$\Delta p'_{tot} = \sum_N \left(\pm h_i\right) = 0{,}46$$

The second correct solution, obtained by introducing a new flow corrective equal to ΔQ”= -12 l/min and taking into account the direction of currents, is:

$$Q''_{oa} = 323 \ l/\min \qquad Q''_{ab} = 143 \ l/\min \qquad Q''_{cb} = 257 \ l/\min \qquad Q''_{oc} = 437 \ l/\min$$

It then makes a new calculation of the balance of the pressure drops in the mesh and in particular:

$$\Delta p''_{tot} = \sum_N \left(\pm h_i\right) = 0{,}01$$

and, to obtain a better result of the above, it should insert a new corrective flow rate, which, however, turns out to be equal to -0.19 l/min, and that is to be considered negligible.

Design of distribution networks to mesh

Of course, you could achieve the same result with an appropriate software that would run the verification of Cross in a very short time.

The pump has a flow rate of 760 l/min and, on the basis of the calculations of the loss of load up to the node b, which is the most unfavorable, and taking into account the height of suction of -2 m, the pump prevalence must be of at least 35 m.

Design of distribution networks

<u>Design of distribution networks to mesh</u>

Is therefore important to perform dynamic analysis in the situations outside the project. Must be analyzed in the following cases:

a) increase of the flow rate for the increase of the flow rates to the users of 20%. The repetition of the calculation leads to the choice of the pump for the following performance:

$$Q_p = 912 \ l/\min \qquad H = 36 \ m$$

This solution shows an excessive speed in the branch oc, equal to 2.25 m/s, which might suggest an increase in the diameter of the pipe at those nodes. The choice of a diameter DN 80 leads to a lower speed and head required, in this case equal to 34 m;

b) expansion of the network with the introduction of the new user and which carries the pump flow rate at 760 + 150 = 910 l/min. Keeping the pipes DN 70, the new prevalence required at the pump should be 36 m to meet the conditions of node b.