CHAPTER 8

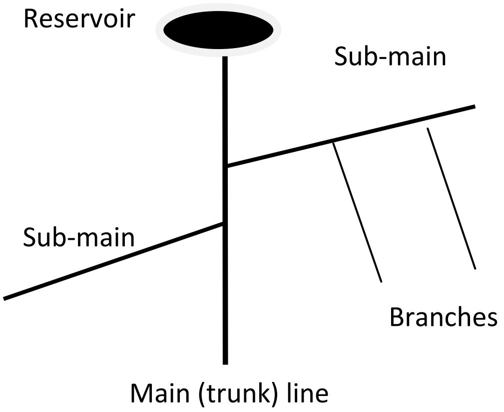
WATER DISTRIBUTION SYSTEMS

- Distribution system is a network of pipelines that distribute water to the consumers.
- They are designed to adequately satisfy the water requirement for a combination of
    - Domestic
    - Commercial
    - Industrial
    - Fire fighting purposes.
- A good distribution system should satisfy the followings:
    - Adequate water pressure at the consumer's taps for a specific rate of flow (i.e, pressures should be great enough to adequately meet consumer needs).
    - Pressures should be great enough to adequately meet fire fighting needs.
    - At the same time, pressures should not be excessive because development of the pressure head brings important cost consideration and as pressure increases leakages increases too.
        - Note: In tower buildings, it is often necessary to provide booster pumps to elevate the water to upper floors.
    - Purity of distributed water should be maintained. This requires distribution system to be completely water-tight.
    - Maintenance of the distribution system should be easy and economical.
    - Water should remain available during breakdown periods of pipeline. System of distribution should not such that if one pipe bursts, it puts a large area without water. If a particular pipe length is under repair and has been shut down, the water to the population living in the down-stream side of this pipeline should be available from other pipeline.
    - During repairs, it should not cause any obstruction to traffic. In other words, the pipelines should not be laid under highways, carriage ways but below foot paths.

DISTRIBUTION SYSTEMS

A. Branching pattern with dead end.
B. Grid pattern
C. Grid pattern with loop.

A. Branching Pattern with Dead End



- Similar to the branching of a tree.
- It consists of
    - Main (trunk) line
    - Sub-mains
    - Branches
- Main line is the main source of water supply. There is no water distribution to consumers from trunk line.
- Sub-mains are connected to the main line and they are along the main roads.
- Branches are connected to the sub-mains and they are along the streets.
- Lastly service connections are given to the consumers from branches.

Advantages:

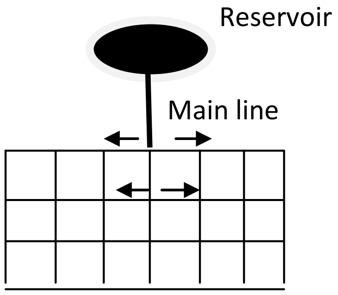
- It is a very simple method of water distribution. Calculations are easy and simple to do.
- The required dimensions of the pipes are economical.
- This method requires comparatively less number of cut-off valves.

However, it is not usually favored in modern water works practice for the following disadvantages.

Disadvantages:

- The area receiving water from a pipe under repair is without water until the work is completed.
- In this system, there are large number of dead ends where water does not circulate but remains static. Sediments accumulate due to stagnation of the dead end and bacterial growth may occur at these points. To overcome this problem drain valves are provided at dead ends and stagnant water is drained out by periodically opening these valves but a large amount of water is wasted.
- It is difficult to maintain chlorine residual at the dead ends of the pipe.
- Water available for fire-fighting will be limited since it is being supplied by only one water main.
- The pressure at the end of the line may become undesirably low as additional areas are connected to the water supply system. This problem is common in many less-developed countries.

B. Grid Pattern



- In grid pattern, all the pipes are interconnected with no dead-ends. In such a system, water can reach any point from more than one direction.

Advantages:

- Since water in the supply system is free to flow in more than one direction, stagnation does not occur as readily as in the branching pattern.
- In case of repair or break down in a pipe, the area connected to that pipe will continue to receive water, as water will flow to that area from the other side.
- Water reaches all points with minimum head loss.
- At the time of fires, by manipulating the cut-off valves, plenty of water supply may be diverted and concentrated for fire-fighting.

Disadvantages:

- Cost of pipe laying is more because relatively more length of pipes is required.
- More number of valves are required.
- The calculation of pipe sizes are more complicated.

C. Grid Pattern with Loops

Loops are provided in a grid pattern to improve water pressure in portions of a city (industrial, business and commercial areas).

Loops should be strategically located so that as the city develops the water pressure should be sustained.

The advantages and disadvantages of this pattern are the same as those of the grid pattern.

DESIGN CONSIDERATIONS

- Diameter ≥ 80 mm.

For pipes with fire hydrants ≥ 100 mm.

- Velocity > 0.6 m/sec.

Common range is 1.0 - 1.5 m/sec.

If velocity < 0.6 m/sec (due to minimum diameter limit) then drain valve is used on that pipe.

- Minimum pressure at the top of the highest floor of a building is about 5m.

According to İller Bankası Regulation:

Population ≤ 50000 then $(P/\delta)_{min}$ =20 m.

Population ≥ 50000 then $(P/\delta)_{min}$ =30 m

It is assumed that tower buildings have their own booster pump.

Maximum static pressure = $(P/\delta)_{max}$ =80 mwc (commonly).

- Design flow rate = Qmax_hr + Qfire

Q fire:

According to İller Bankası Regulation, fire flow and fire storage amount can be calculated as;

∗ If the future population ≤ 10000

Fire flow for main line = 5 L/sec

Fire flow for sub-mains = 5 L/sec

Fire flow for branches = 2.5 L/sec

It is assumed that 1 fire with a duration of 2 hours then amount of water necessary for fire-fighting in the service reservoir:

$$5\frac{L}{sec}x\frac{3600\,sec}{1hr}x2hrs = 36000L = 36m^3$$

∗ If 10000 < the future population ≤ 50000

Fire flow for main line = 10 L/sec

Fire flow for sub-mains = 5 L/sec

Fire flow for branches = 2.5 L/sec

It is assumed that 2 fires with a duration of 2 hours then amount of water necessary for fire-fighting in the service reservoir:

$$5\frac{L}{sec}x\frac{3600\,sec}{1hr}x2hrsx2fires = 72000L = 72m^3$$

∗ If the future population ≥ 50000

Fire flow for main line = 20 L/sec

Fire flow for sub-mains = 10 L/sec

Fire flow for branches = 5 L/sec

It is assumed that 2 fires with a duration of 5 hours then amount of water necessary for fire-fighting in the service reservoir:

$$10\frac{L}{sec}x\frac{3600\,sec}{1hr}x5hrsx2fires = 360000L = 360m^3$$

- Fire hydrants are used on sub-mains to provide a connection for fire hoses to fight fire.
- Fire hydrants should be located at easily accessible locations.
- In Turkey, length of fire hosed is about 50-75m. Therefore, distance between fire hydrants is about 100-150m.
- Sub-mains should be divided into sections and valves should be provided in each, so that any section may be taken out of operation for repairs. For this purpose, gate valves are usually used.
- 3 gate valves are used at all crosses.
- 2 gate valves are used at al tees.
- To remove air from pipelines or to allow automatic air entrance when the pipeline is emptied (in order to prevent vacuum), air release and relief valves are placed at high points.

HYDRAULIC ANALYSIS OF DISTRIBUTION SYSTEMS

Most commonly methods used are:

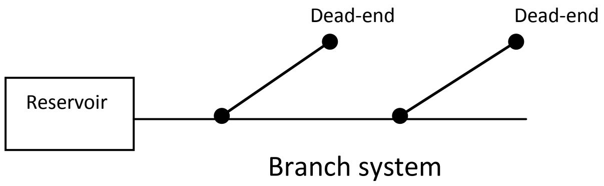
a) Dead-end method

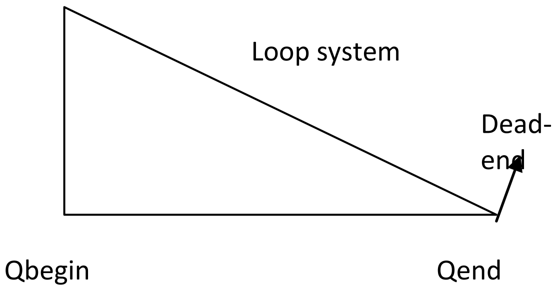
b) Hardy-Cross method

c) Equivalent pipe method

A) Dead-End Method

- Determine the locations of "dead-ends" providing that water will be distributed in the shortest way. At the dead-end points there will be no flow distribution.





- To apply dead-end method for loop systems, convert it to branch system. To do this, a dead-end point is identified for each loop. The location of dead end point is chosen such that distance travelled to reach dead-end point from 2 different directions will almost equal to each other. Because; in a closed loop
$\sum HL_{from\ one\ direction} \cong \sum HL_{from\ other\ direction}$

- Start calculations from dead-ends to service reservoir.
- Calculate the total flowrate to be distributed (Qmax_h + Qfire)
- To calculate design flowrate of each pipe;
    - Q distributed
    - Q begin
    - Q end

  should be calculated.

To calculate Q distributed:

- Population density coefficients (k) are calculated from the areas to where water to be distributed. Population density in each area is determined according to number of stories:

Number of story	1	2	3	4	5
One-sided buildings	0.5	1	1.5	1.75	2
Two-sided buildings	1	2	3	3.5	4

Unit of k = population/m length of pipe

- Equivalent pipe lengths are calculated for each pipe:

$$(L_{eq})_i = k.\ L_i$$

- Distributed flow in unit pipe length:

$$q = \frac{Qtotal}{\sum L_{eq}}$$

- Distributed flow (Qdist) in each pipe:

$$(Qdist)_i = q.\ (L_{eq})_i$$

To determine Design Flow

A) For the pipes having dead-end:

$$Q_{design} = 0.577Q_{dist} + Q_{end} + Q_{fire}$$

B) For the pipes having no dead-end:

$$Q_{design} = 0.55Q_{dist} + Q_{end} + Q_{fire}$$

- Diameter of each pipe is selected providing that velocity should be in the range.
- Head losses through each pipe is calculated by using Darcy-Weisbach or Hazen-Williams equation.

HL calculation according to Darcy-Weisbach:

$$H_L = k.Q^2.L$$

where $$\boldsymbol{k} = \frac{\boldsymbol{f}}{\boldsymbol{D}.\boldsymbol{A}^2.\boldsymbol{2g}}$$

HL calculation according to Hazen-Williams:

$$H_L = k.Q^{1.85}.L$$

where $$\boldsymbol{k} = \left(\frac{\mathbf{1}}{\mathbf{0.278}\boldsymbol{CD}^{\mathbf{2.63}}}\right)^{\frac{\mathbf{1}}{\mathbf{0.54}}}$$

- Piezometric elevations and pressures are calculated. To do this; water level in the reservoir and diameter and length of the main line have to be known.

B) Hardy-Cross Method

- This method is applicable to closed-loop pipe networks.
- The outflows from the system are assumed to occur at the nodes (NODE: end of each pipe section). This assumption results in uniform flow in the pipelines.
- The Hardy-Cross analysis is based on the principles that
    1. At each junction, the total inflow must be equal to total outflow.

       $\sum Q_{inflow} = \sum Q_{outflow}$ (flow continuity criterion)

    2. Head balance criterion: algebraic sum of the head losses around any closed-loop is **zero**.

       $$\sum HL_{clockwise\ direction} = \sum HL_{counter\ clockwise\ direction}$$

- For a given pipe system, with known junction outflows, the Hardy-Cross method is an iterative procedure based on initially estimated flows in pipes. Estimated pipe flows are corrected with iteration until head losses in the clockwise direction and in the counter clockwise direction are equal within each loop.

PROCEDURE:

1. Outflows from each node are decided.
2. Flows and direction of flows in pipes are estimated by considering the flow continuity condition.

   At each node; $\sum Q_{inflow} = \sum Q_{outflow}$

3. Decide the sign of flow direction. Usually clockwise direction (+) and counter clockwise direction (-). Use the same sign for all loops.
4. Diameters are estimated for the initially assumed flowrates knowing the diameter, length and roughness of a pipe, headloss in the pipe is a function of the flowrate Q.

Applying Darcy-Weisbach

$HL = K.\ Q^2$

Where $K = \frac{fL}{D}\frac{1}{2gA^2}$

Applying Hazen-Williams

$HL = K.Q^{1.85}$

Where $K = \frac{L}{(0.278CD^{2.63})^{1.85}}$ for SI units.

Formulae for flow correction, ΔQ

$\Delta Q = \frac{-\sum HL}{2\sum(\frac{HL}{Q})}$ for Darcy-weisbach

$\Delta Q = \frac{-\sum HL}{1.85\sum(\frac{HL}{Q})}$ for Hazen-Williams

5. By using ΔQ value, new estimated flows are calculated.

Q initial	ΔQ	Q new
0.1	+0.001	0.1+0.001
-0.2		-0.2+0.001
-0.3		-0.3+0.001
0.4		0.4+0.001

For pipes common in two loops are subjected to double correction.

	1st loop	ΔQ_1	2nd loop	ΔQ_2
Initially	+1	-x	-1	+y
After correction	+1-x-y		-1+y+x	

6. Computational procedure is repeated until each loop in the entire network has negligibly small corrections (ΔQ).

C) Equivalent Pipe Method

Equivalent pipe is a method of reducing a combination of pipes into a simple pipe system for easier analysis of a pipe network, such as a water distribution system. An equivalent pipe is an imaginary pipe in which the head loss and discharge are equivalent to the head loss and discharge for the real pipe system. There are three main properties of a pipe: diameter, length, and roughness. As the coefficient of roughness, C, decreases the roughness of the pipe decreases. For example, a new smooth pipe has a roughness factor of C = 140, while a rough pipe is usually at C = 100. To determine an equivalent pipe, you must assume any of the above two properties. Therefore, for a system of pipes with different diameters, lengths, and roughness factors, you could assume a specific roughness factor (most commonly C = 100) and diameter (most commonly D = 8"). The most common formula for computing equivalent pipe is the Hazen-Williams formula [1].

EXAMPLE: For the pipe system shown below (Figure 1), determine the length of a single equivalent pipe that has a diameter of 8 inches. Use the Hazen Williams equation and assume that C_{HW} = 120 for all pipes. Solve the problem using the following steps: [2]

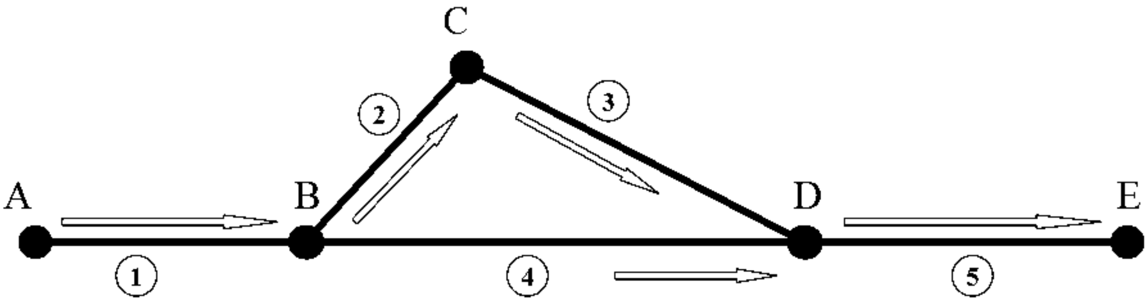


Figure 1. Pipe System for equivalent pipe problem

Table 1. Pipe Data for Figure 1 Pipe System

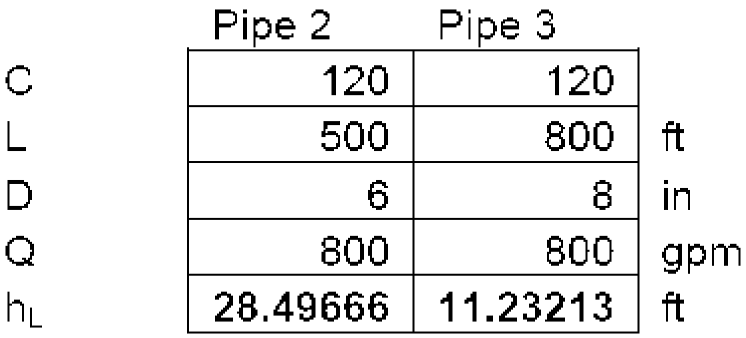
	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	
Length	500	500	800	1000	700	ft
Diameter	12	6	8	10	12	in

a. First determine an equivalent pipe (with D=8 in) for pipes #2 and #3 in series. Use a flow of 800 gpm.

Use the Hazen Williams equation for Q in gpm and diameter in inches.

$$h_L = 10.5 \frac{Q^{1.85} L}{C^{1.85} D^{4.87}}$$

Use this to calculate the headloss in pipe 2 and pipe 3 (recognizing that the flow in pipe 3 must also be 800 gpm).



	Pipe 2	Pipe 3	
C	120	120	
L	500	800	ft
D	6	8	in
Q	800	800	gpm
h_L	28.49666	11.23213	ft

The total headloss is then the sum of these two
H_L total = **39.73 ft**

and the equivalent length for a 8 in pipe is calculated by rearranging the H-W formula and solving for L

$$L = \frac{h_L C^{1.85} D^{4.87}}{10.5 Q^{1.85}}$$
$$\boxed{= 2839\,ft}$$

b. Second, determine an equivalent pipe for pipe #4 and the parallel equivalent pipe from part (a). Use the head loss resulting from the flow for part (a) as the basis for determining the equivalent pipe length (use D=8 in). What is the flow split between these two parallel pipes? (i.e., for 800 gpm through the part (a) pipe, what is the flow in the parallel pipe, and the total flow)

Now that we know the headloss from node B to node D is 39.73 feet, we can determine the flow in pipe #4 by the H-W formula, rearranged as follows:

$$Q = \frac{h_L^{0.54} C D^{2.63}}{3.56 L^{0.54}}$$

= 2526 gpm

Now the total flow between nodes B and D is then the sum:
QB-D = 2526 + 800 = **3326 gpm**

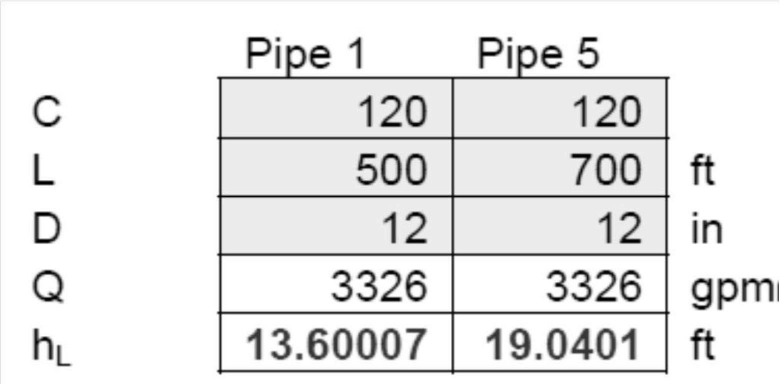
Finally using the H-W equation, you can calculate an equivalent length of an 8 inch pipe that gives the existing headloss with this flow:

$$L = \frac{h_L C^{1.85} D^{4.87}}{10.5 Q^{1.85}}$$

= 203 ft

c. Finally, determine a single equivalent pipe (D = 8 in) for the three pipes in series, pipe #1, the pipe from part (b), and pipe #5.

Next you can use the H-W formula to calculate the headloss in pipes #1 and #5, recognizing that the flow in each must be the same as the flow determined for node B to node D (e.g., 3326 gpm):



	Pipe 1	Pipe 5	
C	120	120	
L	500	700	ft
D	12	12	in
Q	3326	3326	gpm
h_L	13.60007	19.0401	ft

The total headloss is then the sum:
hL = 39.73 + 13.60 + 19.04 = **72.37 ft**

and returning to the H-W equation, we can calculate an equivalent length based on this headloss and to flow:

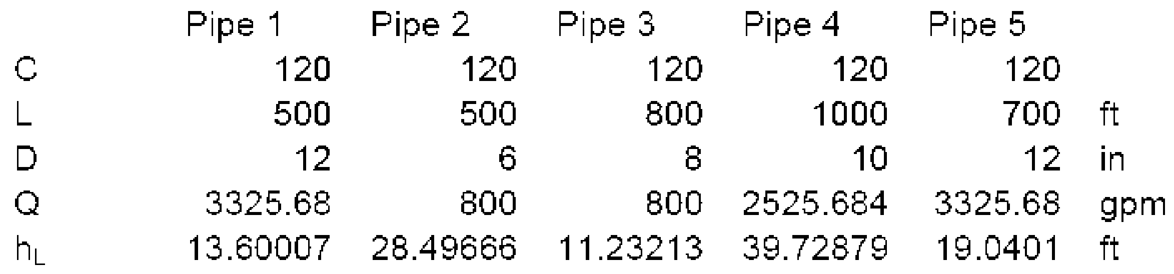
$$L = \frac{h_L C^{1.85} D^{4.87}}{10.5 Q^{1.85}}$$

= 369 ft

d. Show that your pipe is hydraulically equivalent by calculating the head loss for this single pipe and comparing it to the sum of the head losses for pipes in the original system.

Recalculate the headloss in each of the original pipes. Sum the headloss from each node to the next one, recognizing that there are two ways of getting from node B to node D (use either one, but not both).

$$h_L = 10.5 \frac{Q^{1.85} L}{C^{1.85} D^{4.87}}$$



	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	
C	120	120	120	120	120	
L	500	500	800	1000	700	ft
D	12	6	8	10	12	in
Q	3325.68	800	800	2525.684	3325.68	gpm
h_L	13.60007	28.49666	11.23213	39.72879	19.0401	ft

Total H_L: 72.36896 ft

References:

[1]http://www.rpi.edu/dept/chem-eng/Biotech-Environ/Environmental/HYDROLOGY/eq_pipe.html
[2] http://www.ecs.umass.edu/cee/reckhow/courses/371/371hw03/371hw03s.pdf