Design Methodology for Supply Water Distribution Network; Case Study: Al-Hadeka District, Garaboulli-Libya

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ABSTRACT

Pipe network is a hydraulic network containing several or many inter-connected branches where fluid (water) flows through it. This paper presents a design methodology for a supply water pipe network for Al-Hadeka district at Garaboulli-Libya. The proposed network provides water to 150 residential units with an average occupation density of 7 persons per unit. The main objective is to determine the flow rate and pressure head at each individual section of the network in addition to water demand of the region. The governing differential equations were formulated based on the continuity and the energy equations. Hardy Cross Method and EPANET Software were implemented to perform the calculations. Two cases were analyzed and investigated, namely, gravity flow and forced flow. Results of both cases were interpreted and compared. There is a good agreement between the results of both methods, in terms of flow velocities in pipes and pressure heads. These values lie in the allowable range in accordance with the known standards and specifications for water distribution networks. The use of the available software, EPANET, for analysis saves time and effort and gives acceptable results of appropriate precision.

Keywords: Pipe network, Hardy Cross, EPANET, Gravity flow, Forced flow.

1   Introduction

Water distribution networks serve many purposes in addition to the provision of water for human consumption. Piped water is used for washing, sanitation, irrigation and fire fighting. Networks are designed to meet peak demands; in parts of the network this creates low-flow conditions that can contribute to the deterioration of microbial and chemical water quality. The purpose of a system of pipes is to supply water at adequate pressure and flow. However, pressure is lost by the action of friction at the pipe wall and pipe accessories and fittings such as valves, elbows…etc. The pressure loss is also dependent on the water demand, pipe length, gradient and diameter. Several established empirical equations describe the pressure–flow relationship and these have been incorporated into network modelling software packages to facilitate their solution and use. Traditionally, a water distribution network design is based on the proposed street plan and the topography. Various equations have been used in this study

as the continuity equation and the energy equation. Hardy Cross Method and EPANET Software was used to perform the calculations required. The hydraulic analysis for the network is applied to two cases, gravity flow and forced flow. Extensive research work on supply water networks has been carried out in literature. For example, studies as shown in references [1], [2], [3], [4] & [5]. Generally, they focused on designing and analyzing supply water pipe networks by Hardy Cross method and EPANET software. Flow rates and pressure heads at each node and junction in the network are calculated and determined. Comparison of results were also interpreted and discussed.

2   Site Overview

The site is located in Al-Hadeka district at Al-Garaboulli city, with an area of 31125 m² and 150 housing utilities as shown in Figure 1.

Figure 1: Site Overview for Al-Hadeka district at Al-Garaboulli city.

According to population surveys in Libya , in the year 2014 , it was found that the family member average is 7 persons , this was done with the help of population private data of the previous years , this comprehensive population scanning is done regularly every 10 years, amongst the methods used for future population scanning is the Geometric Method. Accordingly, population of this area is approximated to be 1050 persons and Water consumption rate is 270 Litre/day/person, so that the total water demand is about 284 m^3/day [6].

3   Design Methodology

3.1   Hardy Cross Method

Hardy Cross method is an effective method in pipe networks analysis. The Hardy Cross method of analysis is a simplified version of the iteration linear analysis. This method is mainly based on assuming reasonable starting values for water flow rates inside network pipes and their directions according to the proposed loops. Then, the values of flow rates should be adjusted iteratively in order to reach to an optimum and precise approximation. Moreover, the head loss in pipes is evaluated simultaneously. In order to apply this method, the site is divided into many subdivisions and loops as shown in Figure 2.
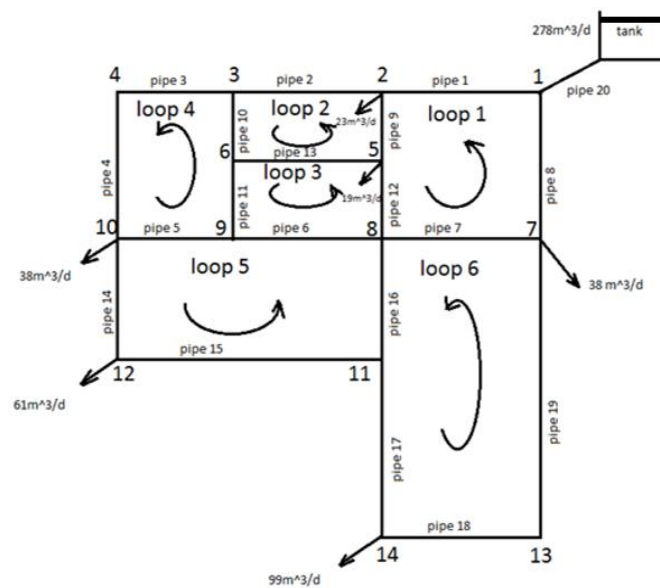

Figure 2: Schematic drawing for pipe network nodes, junctions and loops.

3.2   EPANET Software

EPANET Software, as shown in Figure 3, performs extended period simulation of hydraulics and pipe network analysis. Moreover, it is designed to be applicable also to pressurized pipe networkers. A pipe network consists of pipe, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET evaluates the flow rates of the water in each pipe, the pressure at each node. EPANET provides an integration environment for editing network input data, performing hydraulic analysis, and viewing the result in a variety of formats, these include colour- coded network maps, data tables, time series graphs, and contour plots. EPANET was developed by the Water Supply and Water Resources Division of the U.S. Environmental Protection Agency.
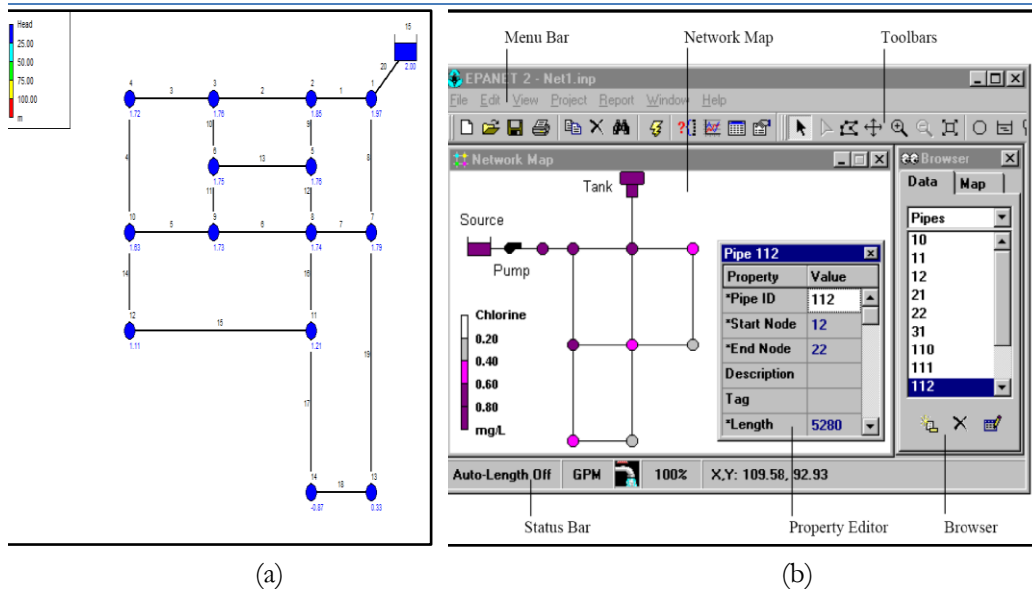
(a)   (b)

Figure 3: Pipe network analysis by EPANET

(a)   Present study pipe network.   (b) EPANET software interface.

3.3   Solution Procedure

Following are the steps carried out to model water distribution network using Hardy Cross method and EPANET;

Step 1: Draw a network representation of distribution system.

Step 2: Edit the properties of the objects that make up the system. It includes editing the properties and entering required data in various objects like reservoir, pipes, nodes and junctions.

Step 3: Describe how the system is operated.

Step 4: Select a set of analysis option.

Step 5: Run a hydraulic analysis program/software.

Step 6: View the results of the analysis which can be viewed in various forms i.e. in the form of tables or graphs.

In addition, the pipe network design and operating conditions for this study according to known standards and specifications, [6] are as follows;

- Flow velocity inside pipes ranges from (0.1 to 1.5) m/s.
- The allowable pressure at nodes ranges from (1.5 to 3) bar.
- Pipe diameters range from (32 to 110) mm.
- Pipe material is HDPE can withstand pressure up to 6 bar.

In order to simplify the analysis, some assumptions are also considered as follows;

- Secondary losses inside pipe network fittings and other accessories are assumed to be negligible.

- Pipes are located at the same level inside the study area.

Storage tank capacity of 900 m³ provides water to site at least for 3 days in case of emergency.

4   Results and Discussion

The hydraulic analysis for the pipe distribution network is applied to two design scenarios, namely, gravity flow case and forced flow case (using a pump).

4.1   Case I: (Gravity Flow)

In the first case the water level on the reservoir is located just 2 meters above ground surface. Results of Hardy Cross method are shown in Table 1 and Table 2.

Table 1: Output results of water flow rates in pipes.

Link ID	Q (m³/s)	Q (L/s)	Q (m³/day)
Pipe 1	0.001808	1.808	156.2112
Pipe 2	0.000726	0.726	62.7264
Pipe 3	0.000572	0.572	49.4208
Pipe 4	0.000572	0.572	49.4208
Pipe 5	0.000483	0.483	41.7312
Pipe 6	0.00011	0.11	9.504
Pipe 7	0.000351	0.351	30.3264
Pipe 8	0.00141	1.41	121.824
Pipe 9	0.000816	0.816	70.5024
Pipe 10	0.000154	0.154	13.3056
Pipe 11	0.000377	0.377	32.5728
Pipe 12	0.000373	0.373	32.2272
Pipe 13	0.000223	0.223	19.2672
Pipe 14	0.000615	0.615	53.136
Pipe 15	9.1E-05	0.091	7.8624
Pipe 16	0.000619	0.619	53.4816
Pipe 17	0.000528	0.528	45.6192
Pipe 18	0.00062	0.62	53.568
Pipe 19	0.00062	0.62	53.568
Pipe 20	0.00322	3.22	278.208

Table 2: Head values at each node.

Node ID.	Head (m)
1	1.97
2	1.85
3	1.76
4	1.72
5	1.76
6	1.75
7	1.79
8	1.74
9	1.73
10	1.63
11	1.21
12	1.11
13	0.33
14	-0.87

Results from EPANET software are shown in Table 3. Flow rates at each pipe, flow velocity, unit head loss and friction factor are determined.

Table 3: EPANET output results for case I.

Link ID	Flow rate (m³/day)	Velocity (m/s)	Unit Head loss (m/km)	Friction factor
Pipe 1	1.2615	0.40	72.8	0.025
Pipe 2	95.16	0.22	71.2	0.030
Pipe 3	44.48	0.27	820.	0.031
Pipe 4	44.48	0.17	820.	0.031
Pipe 5	61.42	0.27	2	10.03
Pipe 6	9.401	20.1	130.	40.03
Pipe 7	23.03	0.19	01.1	0.034
Pipe 8	9.7112	0.32	31.8	0.026
Pipe 9	26.17	0.27	631.	0.029
Pipe 10	51.31	20.1	070.	340.0
Pipe 11	13.32	0.14	400.	50.03
Pipe 12	64.33	0.16	430.	40.03
Pipe13	26.81	0.10	160.	10.04
Pipe 14	05.35	0.48	58.7	0.029
Pipe 15	95.7	0.12	50.8	0.041
Pipe 16	7453.	0.50	888.	0.029
Pipe 17	5245.	0.65	219.8	0.029
Pipe 18	4853.	0.77	6326.	0.028
Pipe 19	4853.	0.49	888.	0.029
Pipe 20	278.00	0.34	1.26	0.024

From above results, Table 2 clearly shows that at node no. 14, the value of pressure head is negative. This means that the pressure at this node is less than atmospheric pressure which in turn implies that water will not reach the node and hence it is clear that the height of the elevated reservoir in case I, is undersized. Therefore, the water reservoir should be located at higher elevation. For this purpose, the tank is elevated at 20 m above ground surface level, this is considered as case II.

4.2   Case II: Gravity Flow using Elevated Tank

Because of the negative pressure in the case I, the tank height will be change to 20 m above ground. The obtained results of both Hardy Cross and EPANET are shown and compared in Table 4 and Table 5.

Table 4: Comparison of results for pressure head in case II.

Node ID	Head, H-C (m)	Head, Epanet (m)	Error, %
1	19.98278	19.97	0.06397
2	19.89224	19.85	0.212357
3	19.83574	19.76	0.381859
4	19.81069	219.7	0.457766
5	19.84119	619.7	0.409176
6	19.8304	519.7	0.405418
7	19.86057	19.79	0.355338
8	19.83201	19.74	0.463942
9	19.82799	319.7	0.494182
10	19.76803	319.6	0.698249
11	19.45122	119.2	1.240142
12	19.50449	1119.	2.022568
13	18.81528	318.3	2.579171
14	17.88649	317.1	4.22941

Table 5: Comparison of results for flow rates in case II.

Link ID	Q(m³/day) H-C	Q(m³/day) Epanet	Error, %
Pipe 1	156.2112	1.2615	0.000768
Pipe 2	62.7264	95.16	1.237756
Pipe 3	49.4208	44.48	1.984589
Pipe 4	49.4208	44.48	1.984589
Pipe 5	41.7312	61.42	2.10586
Pipe 6	9.504	9.410	10.5397
Pipe 7	30.3264	23.30	0.021104
Pipe 8	121.824	9.7112	0.027909
Pipe 9	70.5024	26.17	1.07457
Pipe 10	13.3056	51.31	1.5362
Pipe 11	32.5728	13.32	1.359416
Pipe 12	32.2272	64.33	4.38387
Pipe13	19.2672	26.81	3.359077
Pipe 14	53.136	05.35	0.161849
Pipe 15	7.8624	95.7	1.11416
Pipe 16	53.4816	7453.	0.02169
Pipe 17	45.6192	5245.	0.217452
Pipe 18	53.568	4853.	0.164277
Pipe 19	53.568	4853.	0.164277

It should be noted that no negative pressure head values are noticed. The assumption of elevating the water tank to a height of 20 m is reasonable and logic. Moreover, the comparison between the results from Hardy Cross method and EPANET shows a good agreement between results of both methods.

4.3 Case III: Forced flow Using Pump

Another alternative for solving the problem of negative pressure in case I, is based on using a ground water tank equipped with a pump station. In this case, water is forced to flow into the pipe distribution network ensuring suitable water demands and pressure heads values at pipes' nodes. Figure 4 shows the characteristics curve for the chosen pump to be used in the system and analyzed by EPANET Software simulation.
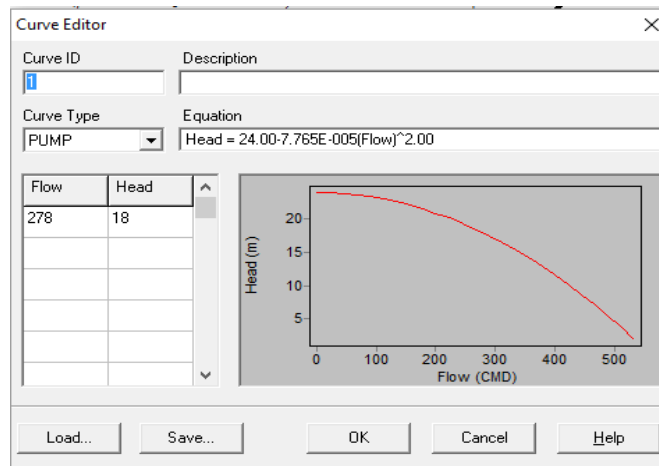

Figure 4: Characteristic curve of the chosen pump.

Table 6 and Table 7 show the results for case III when a pump is considered in the pipeline.

Table 6: Results for demand and pressure head at each node for case III.

Node ID	Demand (m³/day)	Head (m)
1	0	20
2	23	19.87
3	0	19.78
4	0	19.74
5	19	19.79
6	0	19.78
7	38	19.82
8	0	19.77
9	0	19.76
10	38	19.66
11	0	19.24
12	61	19.13
13	0	18.35
14	99	17.15

Table 7: Results for flow rate, velocity, unit head loss and friction factor for case III.

Link ID	Flow rate (m³/day)	Velocity m/s	Unit Head loss m/km	Friction factor
Pipe 1	156.21	0.40	2.84	0.025
Pipe 2	61.95	0.22	1.28	0.030
Pipe 3	48.44	0.27	0.93	0.031
Pipe 4	48.44	0.17	0.93	0.031
Pipe 5	42.61	0.27	1.73	0.032
Pipe 6	10.49	0.12	0.46	0.038
Pipe 7	30.32	0.19	1.16	0.034
Pipe 8	121.79	0.32	1.86	0.026
Pipe 9	71.26	0.27	1.59	0.029
Pipe 10	13.51	0.12	0.48	0.042
Pipe 11	32.13	0.14	0.57	0.037
Pipe 12	33.64	0.16	0.61	0.033
Pipe13	18.62	0.10	0.49	0.042
Pipe 14	53.05	0.48	8.74	0.029
Pipe 15	7.95	0.12	0.89	0.041
Pipe 16	53.47	0.50	8.94	0.029
Pipe 17	45.52	0.65	19.89	0.029
Pipe 18	53.48	0.77	26.78	0.028
Pipe 19	53.48	0.49	8.92	0.029

In the case of water supply from ground tank using a pump, case III, it is found that the pressure head at the end of each junction (node) and corresponding value of flow rate are acceptable and ensure providing water to consumers. Furthermore, it can be noticed that the velocities at each pipe in Table 7 are within the recommended range stated in the relevant standards.

5   Conclusions

In this paper, Hardy Cross Method and EPANET software were used to perform the required calculations and the hydraulic analysis for the network under study, Al-Hadeka district at Garaboulli city –Libya. Two Scenarios were proposed, gravity flow and forced flow. For gravity flow, Case I, water level in the storage tank is assumed to be 2 meters above the ground. Results show that there is a deficiency in providing the required water quantities at some nodes in the network. In order to correct the situation, storage tank elevation is adjusted to 20 meters above ground, case II. Results indicate that the flow rates and pressure heads among the junctions of the pipe networks are acceptable and lie in the allowable values.

Another alternative is to apply a pump in the network, case III, forced flow. As expected, there is a better output results in terms of flow rates, velocities in pipes and pressure heads at the required points of demand. The obtained values were found to be within the allowed ranges

in accordance with the specifications and standards for water distribution networks. Finally, the use of available software for analysis saves time and effort and gives results of appropriate precision.

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