LOCALLY PRACTICED NETWORK OPERATIONAL METHODS AND WATER QUALITY IN DISTRIBUTION SYSTEM

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ABSTRACT. Due to discontinuity and unsteadiness of supplied potable water, water consumers were forced to adopt the double-reservoir system. This type of system is posing a threat to public health due to inefficient and irregular maintenance in addition to the possibility of contamination from nearby cesspools and septic tanks. This study evaluates the feasibility of replacing the existing double-reservoir system in Al-Khaledyyah area with a pressure system . Based on the results of the study, it has been found that the existing network system in Al-Khaledyyah area can be operated as a pressure system even under low draft conditions. In addition, the water quality analysis showed no signs of contamination in Al-Khaledyyah area which might be attributed to the short storage period (retention time) and newly constructed buildings.

1. INTRODUCTION

A water distribution network supplies potable water to municipal and industrial sectors. It is an expensive piece of equipment. The adequacy of the distribution system is determined by the pressures that exist at various points in the system under conditions of operation. Design for high pressures, that are unnecessary, is too costly. A common practice in most Saudi cities is the discontinuous pumping and operation of the network system under conditions other than the originally designed ones. This discontinuity and unsteadiness of flow causes a fluctuation of pressure from time to time and hence supplying water to the desired elevation in buildings is difficult. Instead, people have adopted the double-reservoir system to overcome this problem. However, the commonly used double-reservoir system is posing a threat to public health due to the inefficient and irregular maintenance in addition to the possibilities of lower reservoir contamination from nearby cesspools. This study aims to evaluate and compare the feasibility and adequacy of the two forementioned systems, namely the double-reservoir system and the pressure pipe system. A simulation model based on the Hardy-Cross method will be used to simulate the flow distribution in both systems. The simulation was carried out using the Al-Khaledyyah water distribution network in Medina. The pipe system was originally designed as a pressure system, but due to shortages in water supply and the deterioration of the old part of the system, it is impractical to use the system according to its intended design. This type of arrangement is costly to the consumer and wasteful of the invested sums used to build the pipe pressure system.

1.1 Existing conditions:

Certain problems of operational conditions in Medina can be listed as follows:

1- the city is expanding rapidly which calls for the construction of new parts of the network taking in consideration the available boundary conditions and constrains.

2- the old portion of the network has deteriorated with time, and some parts of the system have no layout maps and design specifications.

3- the pipe material used in the network differs and pressure requirements are different.
4- it is not possible to have a continuous water supply as it is supplied by rotation due to the imbalance in the supply/demand requirement.

As can be seen from the above information, it is impossible to run the existing pipe network as a pressure system. The common practice is to supply water with minimum pressure just enough for the water to reach the lower reservoir in houses from which it is pumped to the overhead reservoir. Only about 30% of the city is served with sewer systems.

2. BACKGROUND

2.1 Waterworks and methods of analysis

A waterworks distribution system includes a main pumping station or main distribution reservoirs as well as other parts of a conveying system such as: pipes, valves, hydrants; reservoirs for storage, equalizing, and distribution purposes; house connection pipes, and meters. The layout of distribution systems could be one or a combination of more than one type of the following: circle, gridiron, and tree systems layout.

The adequacy of a distribution system is determined by the pressures that exist at various points in the system under the conditions of operation. Designing for pressures that are unnecessarily high is too costly. Since more than half of the cost of a waterworks lies in the distribution system, it is essential that it is designed economically.

Methods used in the analysis of pressure distribution systems can be listed as follows:

(1) The equivalent-pipe method which omits and combines pipes to form parallel- and series-compound pipes [1];
(2) The cut-circle or cut-contour methods which involves the hypothetical cutting for pipes tributary to a point on the distribution system [2];
(3) Graphical methods described by Freeman, Palsgrove, Kingsbury, and Rennelaer Polytechnic Institute [3];
(4) the Cobb three-dimensional method which involves the manipulation of a set of five prepared disks [2];
(5) Hardy-Cross method of successive approximation or head balance method which involves making successive corrections to assumed flows in a network [5];
(6) Nodal method (Quantity Balance method) modified by R.J. Cornish [4] which involves making successive corrections to assumed pressure head at junctions in the network initially not known.
(7) Linear theory method which involves the solution of a set of equations describing flow and head balance simultaneously [11];
(8) Newton-Raphson method which involves making corrections to assumed heads or flow rates over the whole network simultaneously [7].

2.2 Computer Program

A computer program called "KYPIPE" was developed at the University of Kentucky (1985). The program was written in Fortran language and can be processed on a main frame, mini- or microcomputer. The program is capable of simulating steady state pressure and flow in pipe distribution systems, as well as an extended period simulation considering water level variation in storage tanks over the simulation period. The program is used to simulate pressures and flow rates in an existing pipe system. To obtain reliable results on which operational recommendations can be based, it is necessary to calibrate the computer model. The calibration is made by initially adjusting some parameters such as pipe roughness so the system pressures predicted for certain conditions are in general agreement with field measurements. Different roughness coefficient C (i.e, in William-Hazen Formula) values of 100, 120, 130, and 140 along with pipe size adjustments were implemented in the calibration process and the obtained pressures were compared with those pressures measured at some selected fire hydrants throughout the network which have pressure values of 1.0 to 1.3 bars. The program is capable of changing all roughness values by a constant factor which makes it easier to perform the calibration. The data needed for simulation includes physical characteristics of the pipe system components, pressure and flow requirements imposed on the system. An IBM PC version of the program is implemented in this research.

3. SIMULATION OF THE HYDRAULIC SYSTEM

3.1 Site Description

Al-Khaledyyah area is located next to the housing project on the east of Medina. It is part of Al-Harra Al-Shargeyah district that covers an area of 141 Ha. It contains about 1492 housing lots. The highest ground level along the periphery is 642.3 m. The nearest point to the 700 mm pipe line located along the Green Belt street is 1920 m. The area is showing rapid growth where the housing project was completed and new housing areas next to Al-Khaledyyah are built such as Hada with 184 house lots and Unayzi with 406 houses lots. However, the water network for these newly developed areas has not been constructed yet. The water supply main available for these areas is a 700 mm pipe line.

3.2 Simulation, Results and Discussion

3.2.1 Data used in simulation

The data and information used in the analysis are listed in Table 1 below.

3.2.2 Design of the network in Al-Khaledyyah

Part of Al-Khaledyyah area does not have a water supply network. An extension of the network which serves the housing area ends in the study area. The settlement plan (streets and the housing lots) was used in deciding the pipes' layout. Then the diameters of the pipes in the network were estimated through computer simulation studies for two types of demand, namely: 0.125 lt/sec per house and 0.063 lt/sec per house (i.e., 50% of demand). The estimated demand per house is based on an average water demand of 200 lt/day and allocation of 6 persons per house and with a 4% increase to account for variation in water consumption. The layout of the pipe network along with node numbering is shown in Figure 1.

3.2.3 Pressure and flow simulation under different loading conditions

Several computer runs were conducted to test the following:

1- The influence of different values of the constant pressure head at the supply node on the flow and pressure distribution throughout the network.
2- Pipe sizing of the main lines in the network and its effect on the velocity and pressure distribution.

<u>First run:</u>
A water demand of 0.125 lt/sec per house , and certain pipe sizes shown in Table 2 (i.e, 1st. pipe size selection) were considered. All pipes have a diameter of 100 mm unless specified.

<u>Second run:</u>
Half of the water demand of the first run (i.e., 0.063 lt / sec per house) and certain pipe sizes shown in Table 2 (i.e, 1st. pipe size selection) were considered.

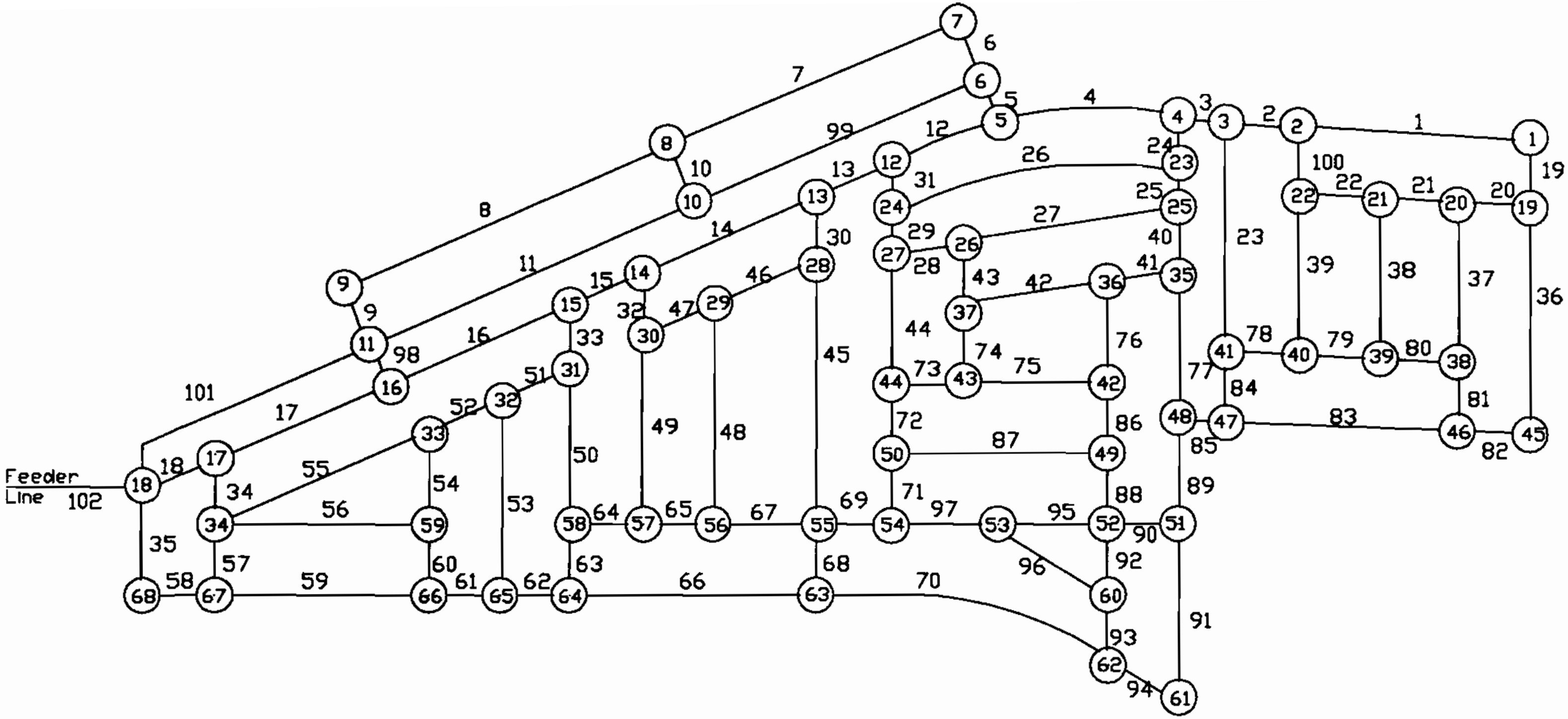

Figure 1. Pipe Network Layout

Third run:
Half of the water demand of the first run (i.e., 0.063 lt/sec per house) and different pipe sizes shown in Table 2 (i.e, 2nd. pipe size selection) were considered.

Table 1. Data prepared for simulation

Parameter	Value
No. of housing lots	1,492
No. of house connections	462
Highest ground level	642.3 m
Water demand/ house	0.125 lt/sec
Pipe roughness	1 mm
Service pressure at house connection	1.5 bars
Capacity of underground reservoirs of houses	20 m^3
Feeder line:	
Length of part 1	700 m
Diameter of part 1	250 mm
Length of part 2	1220 m
Diameter of part 2	500 mm
Static head	22.3 m
Fixed grade at supplying reservoir	660 m

Table 2. pipe sizes at inlet of the network

Pipe No.	17	18	34	35	58	59	61	62	66	68	69	71	101
1st pipe size, mm	150	200	150	200	200	200	200	200	200	150	150	150	250
2nd pipe size, mm	150	200	100	150	100	100	100	100	100	100	100	100	250

Other pipes in the network have equal diameters of a 100 mm.

3.2.4 Results and Discussion

The results of the simulations are shown in Tables 3, 4, and 5. The pipe lengths required for the selected diameters are listed in Table 3 which shows that the higher demand requires longer pipes of bigger diameters. The bigger and longer the pipe the more the unnecessary cost added to system.

The maximum and minimum values of pressure head and velocity throughout the network are presented in table 4. Table 4 shows that the pressure range required to deliver the water through pipes is higher for the lower demand case than that of the higher one. Also, the velocity range for the case with shorter pipes is higher than that of longer pipes with larger diameters. The zero velocity value shown in Table 4 is an indication of a closed pipe case with no flow or improper demand distribution at nodes surrounding the pipe. Values of the constant head grade at supply node and pressure head at the remote node are presented in Table 5. Tables 4 and 5 show that the pressure is sufficient enough for the network to operate under lower demand. Also, it shows the head losses computed between the source node (i.e, node

18) and the dead end node (i.e, node 20). They demonstrate that the head of 1 to 2 bars at the source node is enough for discharging water throughout the area under consideration.

Table 3. Results of simulation

Demand per house	0.063 lt/sec (from 3rd. run)	0.125 lt/sec (from 1st.run)
Pipe diameter	Length	Length
100 mm	9485 m	8545 m
150 mm	270 m	450 m
200 mm	70 m	830 m
Total Length	9825 m	9825 m

Table 4. Maximum and Minimum Pressure and velocity values

0.125 lt/s per house (from 1st.run)				0.063 lt/s per house (from 2nd.run)				0.063 lt/s per house (from 3rd. run)			
Pressure head, m		Velocity, m/s		Pressure head, m		Velocity, m/s		Pressure head, m		Velocity, m/s	
Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
12.75	16.23	0.01	1.2	17.63	18.67	0	0.62	15.86	18.67	0	0.77

Table 5. Pressure head at supply and remote nodes and losses to dead end node

	Supply node (#18)	Remote node (#1)	Remote node (#45)	Max. head loss,m
1st.run case	16.23 m	12.75 m	12.75 m	3.55
2nd. run case	18.67 m	17.63 m	17.63 m	1.38
3rd. run case	18.67 m	15.86 m	15.86 m	2.84

4. WATER QUALITY INVESTIGATION

A sampling station within Al-Khaledyyah district have been selected for sampling and monitoring programs to evaluate the impact of both the pressure and the double reservoir systems on the quality of drinking water in the city.

Grab samples were collected from the sampling station. One sample was collected from the influent water pipe to the house. This sample was assumed to represent the water quality in the high pressure water supply system. The second sample was obtained from a water tap within the house (the sampling station) to represent the water quality in a double reservoir water supply system. The retention time (storage time) in the ground water reservoir at the *sampling station is about 24 hours.*

The sampling station was monitored at three different periods (15/4, 21/6, 10/8/1414H) to ensure the reliability and accuracy of the results. About 2 liters of representative samples were collected in plastic bottles from each sampling point for physical and chemical analysis. Samples for biological testing were collected in sterilized glass bottles. All samples were preserved and transported immediately to the Sanitary Engineering Laboratory, King Abdulaziz University, Jeddah, for analysis.

4.1 Analytical Methods

Heavy metals, specifically iron, and copper concentrations in water samples were determined using a GBC 905 model Atomic Absorption instrument. Nitrate was determined using the Ultraviolet Spectrophotometric Screening method (section 418), Standard Methods [1]. Nitrite was measured by the calorimetric technique, using diazotized sulfuric acid (section 419) Standard Methods. The pH values were measured using a Model 610A Fisher pH meter. All other parameters were measured according to the procedure described in the Standard Method [1].

The total coliform concentrations were measured by the membrane filter technique. All the glassware used was sterilized in a hot air oven at 170°C for two hours. The dilution bottles were filled with 100 ml of dilution water, and they were sterilized in an autoclave at 121°C by heating for 15 min. Filter holders were sterilized in a UV sterilizer by exposing them to UV light for at least three minutes. The procedure described in the Standard Methods [1] for the determination of fecal coliforms by MF technique was followed.

4.2 Results and discussion

The results of the chemical analysis obtained for all samples were checked for completeness and accuracy using Cation-anion balance. In most cases the accuracy of the chemical analyses was within the allowable limits, hence, the water analysis was acceptable. The chemical analysis was repeated for samples having unacceptable results. Also, the meq/l bar graphs for samples obtained in the first collection period, showing the hypothetical combinations of various compounds in the water are shown in Figure 2. As can be depicted from the Figure, the influent water is composed mainly of calcium bicarbonate, calcium sulfate, magnesium chloride and sodium chloride.Al-Khaledyyah district is an unsewered area, and hence, septic tanks are used for wastewater disposal. The water is supplied by public network. Results of water quality analysis (Table 6) showsthat the water is acceptable for drinking purposes, and no bacteriological contamination has been found.

The sampled buildings are relatively new and the conditions of both groundwater tanks and septic tanks are good . The variations in the influent water quality during various sampling periods is mainly due to the variation in water quality at the source, where desalinated water is mixed with well water. A number of wells are used, on alternate basis, for this purpose. Hence, the quality of the raw water is dependent on the quality of the well water used for conditioning purposes. Comparison between water quality in influent pipe and tap water quality has indicated a slight variation which may be attributed to the impact of the storage period and variation of influent water quality with time. However, the water quality is acceptable for drinking purpose according to both MEPA and WHO drinking water standards.

5. CONCLUSION

The use of mathematical models can help engineers and planners in designing water supply systems as well as analyzing existing ones for better operational strategies. Due to the high cost of water distribution systems, alternative systems were developed and evaluated with such models seeking an optimal workable design. Based on the results and outcome of the computer modeling and the water quality testing and analysis, the following conclusions were drawn:

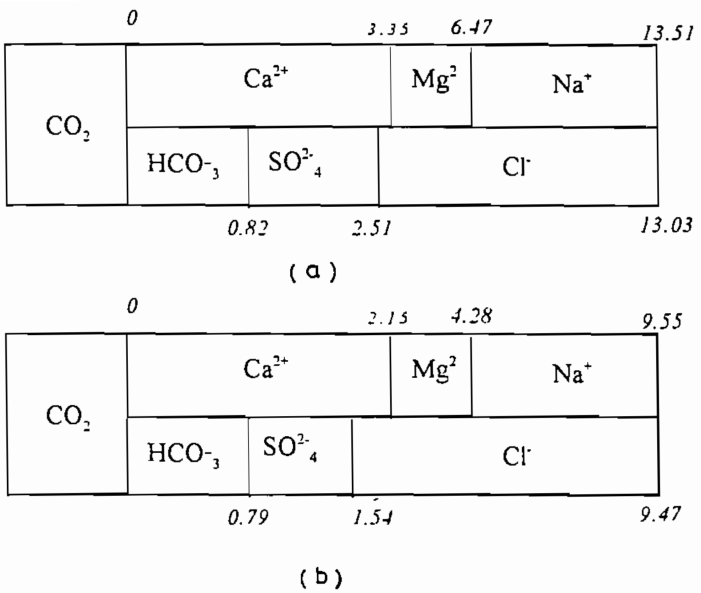

Figure 2. Bar graph for water quality in Al-Kaledyyah district (first collection) showing the hypothetical composition: (a) Influent water sample (b) Tap water sample

Table 6. Water quality in Al-Khaledyyah area

Collection Date	15/04/1414 H		21/06/1414 H		10/08/1414 H	
Chemicals	Influent	Tap	Influent	Tap	Influent	Tap
TDS, mg/l	777	1,046	605	515	700	650
Conductivity, umho/cm	90	120	-	-	-	-
Turbidity, NTU	0.4	0.5	0.6	0.6	0.9	0.9
pH	7.5	7.4	7.75	7.8	7.8	7.8
Calcium	43	67	18.4	16.8	19	16.9
Magnesium	26	38	33.7	27.23	33	28
Sodium	121	162	163	164	170	166
Potassium	1.64	2.1	1.45	1.5	1.6	1.5
Alkalinity, mg/l as $CaCo_3$	-	80	62	66	72	77
Sulphates, mg/l	36	81	94	109	95	110
Chloride, mg/l	267	373	270	220	256	219
Nitrate, mg/l	11.22	23	18.4	14.84	22	20
Nitrite, mg/l	nil	nil	nil	nil	nil	nil
Iron, mg/l	0.26	0.25	0.75	0.8	0.75	0.09
Copper, mg/l	0	0.12	0.05	0.03	0.05	0.03
Total Hardness, mg/l as $CaCo_3$	214	310	184	154	180	165
Total Coli /100ml	nil	nil	nil	nil	nil	nil
Total Coli /100ml	nil	nil	nil	nil	nil	nil

1) The pressure system is very convenient and reliable and can operate well even under lower water drafts.
2) Economically, it is quite a waste of money and resources not to operate the pipe network system under pressure as it was originally designed.
3) The water quality in Al-Khaledyyah district (unsewered and uses double reservoir water supply system) was found acceptable for drinking purposes according to both WHO and MEPA standards. No bacteriological contamination has been detected in all samples.
4) The use of the double reservoir system did not cause a significant impact on the water quality, provided that the storage facility is well maintained and storage period is kept at a minimum.

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