2011 International Conference on Environment and BioScience
IPCBEE vol.21 (2011) © (2011) IACSIT Press, Singapore

A suggestion of Optimization Process for Water Pipe Networks Design

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Abstract. The main aim of the present study is to produce a suggestion of optimization process of water pipe networks design through studying the effect of pipe and pump costs on the optimization process in a network with a predetermined layout. In the present study, computer simulation and analytical solutions have been used for the optimum design of pipe diameters of water distribution pipe networks, supplied from a groundwater source by pumping. The study has revealed that for improving the design diameters, all of the cost parameters should be included in the process.

Keywords: optimum network, water pipe network, cost parameters.

1. Introduction

A water distribution network is a system of hydraulic elements contains (pipes, reservoirs, pumps, valves of different types), which are connected together to provide the quantities of water within prescribed pressures from sources to consumers. In the cost analysis of water–distribution schemes, there may exit numerous arrangements of pipe sizes within the network. However, the choice of the optimal arrangement should be based on reasonable economic considerations. The optimization of pipe networks has been studied and various researchers had proposed the use of mathematical programming techniques in order to identify the optimal solution for water distribution systems. The optimal solution always means minimum cost of the network. The diameter corresponding to this minimum cost is known as the economic pipe diameter. Featherstone et.al.1983, presented a method to get the minimum cost of the network by equating the first derivative of the total cost equation with zero, [2].

2. Proposed System for the Study

As a proposal of the study, it is suggested for the study to include the same aquifer system and suggested layout of pipe network studied before in a previous study, [4]. The suggested layout of pipe network is given as shown in Fig.1. In the previous study, equal and unequal diameters pipe networks were assumed, the optimized commercial diameters for the initial assumed diameters determined using the same procedure of Featherstone 1983, (derivative method),and including all cost parameters in the optimization process, as shown in Table 1.

3. Effect of Pipe Cost in the Optimization Process

The University of Pretoria together with the Water Research Commission has developed the GENETIC ALGORTIHM NETWORK OPTIMISATION PROGRAM (GAWUP), with which the optimum diameter(s) of a water distribution network can be determined. THE GANEO program is part of the Genetic Algorithm Water Utility Programs software package. The GANEO program utilizes genetic algorithms in the optimization of the water distribution systems (new networks or improvements to existing networks), [9]. This is adding on package to the public domain hydraulic modeling package EPANET. With GANEO a new

network can be designed or an existing network can be improved by adding parallel pipes between certain nodes. The GANEO software has been tested against a number of benchmark problems and provided promising solutions. Therefore; a suggested case study model used for simulation in EPANET software is entered as a main network file in the GANEO software data, which including suggested layout of pipe network and lengths of pipes. The program can be downloaded from the Water Research Commission or the University of Pretoria website, http://www.sinotechcc.co.za/Software/GAWUP/gawup.html, [9].
The diameters obtained from the running GANEO's software for the best solution are shown in Table 1

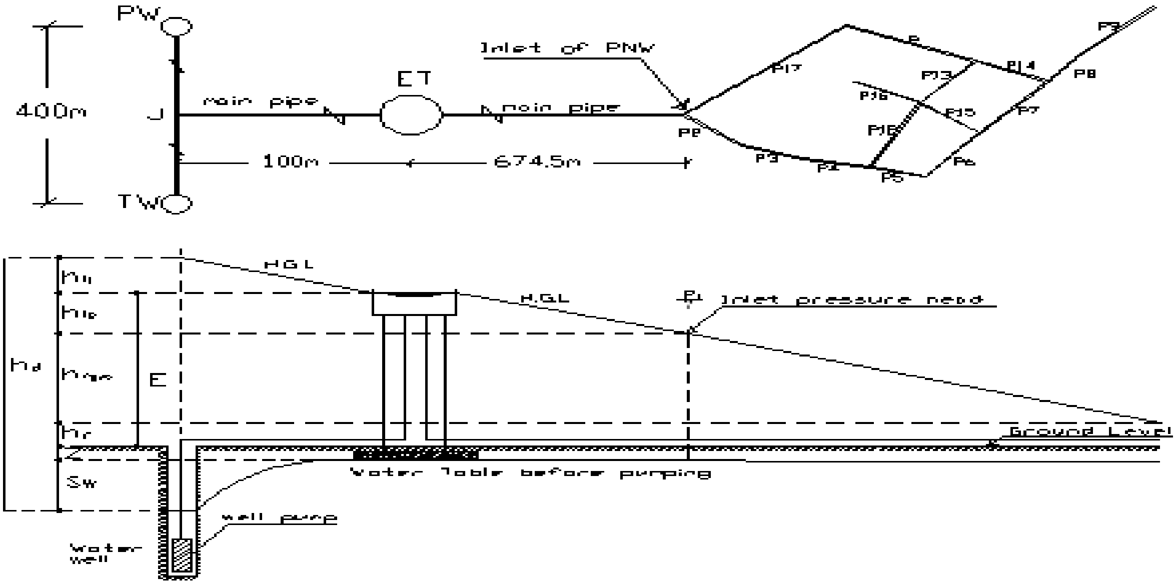


Fig. 1: Suggested layout of pipe network and setting of pump, elevated tank, main pipes and P.N.W.

Table 1: Diameters of the optimal networks by "Derivative Method", [4] and GANEO's results

Pipe Ref. No.	**Length (m)**	**Including all cost parameters**		**Considering pipe cost only**
		Commercial optimized diameters, (mm)		**Commercial optimized diameters, (mm)**
		N_{35} P.N.W	**Sch (3) P.N.W**	
P2	179	296.6	296.6	296.6
P3	547	296.6	296.6	296.6
P4	281	296.6	296.6	296.6
P5	236.5	211.8	235.4	169.4
P6	254	188.2	211.8	188.2
P7	362.5	188.2	211.8	188.2
P8	363.5	188.2	188.2	150.6
P9	338	188.2	188.2	131.8
P12	257.5	235.4	211.8	150.6
P13	345.5	188.2	150.6	103.6
P14	233.5	150.6	103.6	84.6
P15	235	103.6	103.6	84.6

where: N_{35} P.N.W and Sch (3) P.N.W refer to the lowest cost networks in the previous study.

For comparison purpose, the results of optimal diameters, global costs and savings using GANEO's software for the suggested layout are given in Table 2.

Table2: Comparison of GANEO's software and derivative methods for global costs and cost savings achieved in N35 P.N.W and Sch (3) P.N.W

Cost and Cost saving	Commercial optimized diameters, (mm) , "Derivative method"		Commercial optimized diameters, (mm) "GANEO's solution"
	N_{35} P.N.W	Sch (3) P.N.W	
Pipe Cost, (LE)	979,125.4	977,429.2	935,492.6
Global Cost, (LE)	3,521,654.5	3,520,818.5	3,917,420.0

Pipe cost Saving % Compared with N_{35} P.N.W Sch (3) P.N.W	 ----- -----	 ------ ------	 4.5 % 4.46 %
Global cost Saving % Compared with N_{35} P.N.W Sch (3) P.N.W	 ----- -----	 ------ -------	 -11.26 % -11.24 %

Investigation of Table 2 shows that:

- The diameters reached by GANEO's solution are smaller than those obtained by the derivative method, since the first depends on pipe cost only, a condition which is verified at reduced diameters.
- GANEO's solution for both schemes shows nearly pipe cost savings about 4.5 %.
- For global costs, the cost savings are nearly equal but have negative signs. This means that the global cost according to GANEO's are much larger than those obtained by the derivative method. However, the smaller diameters reached by GANEO's cause increase of operating head of pump, pumping cost and pump cost.

4. Excluding the Pump Cost

The cost parameters calculated according to the Egyptian local market, and the same formula of the total cost used before in the previous study, [4].are given as follows:

Total $Cost_{P.N.W}$, $C_T = C_{pi2} + C_{p1} + C_{p2} + C_{we} + C_{et} + C_{Lm} + C_{tr} + C_{in}$ (1)

Pipe cost, $C_{pi2} = 1423 * L * D^{2.12}$ (2)

$$C_{Pi2} = 1423 * L_i * \left(\frac{0.33 * f_i * Q_i^{\,2}}{S * (24*60*60)^2} \right)^{0.424} \text{, where} \quad D = \left(\frac{0.33 * f_i * Q_i^{\,2}}{S * (24*60*60)^2} \right)^{0.2}$$

For all pipes,

$$C_{Pi2} = 0.0579 * \sum_{i=1}^{i=m} \left(\frac{L_i * f_i^{\,0.424} * Q_i^{\,0.848}}{S^{0.424}} \right) \quad (3)$$

Where:

m: is the number of pipes (*m* = 12), Q_i *:* is the individually pipe discharge (m^3/day), S: hydraulic gradient

f_i : is the friction factor (function of *K*/D and Reynolds number), where *k* is the roughness height, [7]

Pumping cost = $C_{p1} = A_1 * Q_t * H_d$, A_1: is unit cost of pumping =2.984 LE/(m^3/day)/ m_{Lift}

Pump cost = $C_{p2} = A_2 * Q_t * H_d$, A_2: is unit cost of pump =0.6 LE/(m^3/day)/ m_{Lift}

Well cost = C_{we} = 160,000 LE

Elevated tank cost = $C_{et} = C * Q_t^{\,0.77}$, C: is the cost coefficient of elevated tank= 450

Treatment cost = $C_{tr} = C_2 * Q_t^{\,0.65}$, C_2: is the cost coefficient of treatment = 520

Inclusive cost = $C_{in} = C_3 * Q_t^{\,0.54}$, C_3: is the cost coefficient of inclusive = 3100

Labor and maintenance cost = $C_{Lm} = C_1 * Q_t^{\,0.47}$, C_1: is the cost coefficient of labor and maintenance = 5000

Then, the general formula for the total cost after excluding the pump term is given as following.

$$C_T = 0.0579 * \sum_{i=1}^{i=m} \left(\frac{L_i . f_i^{\,0.424} . Q_i^{\,0.848}}{S^{0.424}} \right) + A_1\, Q_t\, H_d + 160000 + C\, Q_t^{0.2} + C_1\, Q_t^{0.47} + C_2\, Q_t^{0.65} + C_3\, Q_t^{0.54} \quad (4)$$

In the equation (4), the value of operating head H_d can be expressed as:

$H_d = S_w + Z + h_r + h_{L1} + h_{L2} + h_{fmax}$

The previous equation can be expressed as follows:

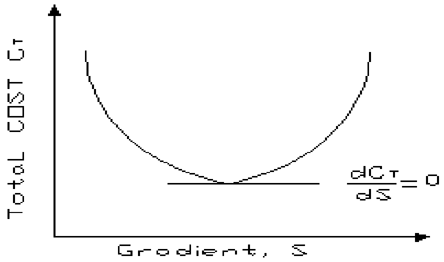
$H_d = S_w + Z + h_r + h_{L1} + h_{L2} + S\, L_{sh}$

In which S= the hydraulic gradient of the shortest flow line, of length L_{sh}, leading from the point of pressure head elevation over the entire network. The basis of the optimization technique is that the optimal design is obtained by equating hydraulic gradients between adjacent nodes to a hypothetical value S, and then equation (4) becomes:

$$C_T = 0.0579 * \sum_{i=1}^{i=m} \left(\frac{L_i . f_i^{0.424} . Q_i^{0.848}}{S^{0.424}} \right)$$

$$+ A_1 Q_t (S_w + Z + h_r + h_{L1} + h_{L2} + S L_{sh}) + 160000 + C Q_t^{0.77} + C_1 Q_t^{0.47} + C_2 Q_t^{0.65} + C_3 Q_t^{0.54} \quad (5)$$

Equation (5), now involves two variables, namely S as the independent variable, and C_T as the dependent variable. This equation can be solved in C_T for different values of S; the result is shown in Fig.2 which shows the total cost, C_T, has a minimum value where $dC_T/ d S$ equals zero. Thus the value of S can be calculated by equating the first derivative of equation (5) to zero



$$0.424 * 0.0579 * \sum_{i=1}^{i=12} L_i \frac{f_i^{0.424} * Q_i^{0.848}}{S^{1.424}} = 2.984 * 836.5 * Q_t$$

$$S = \left(\frac{9.84 * 10^{-6} * \sum_{i=1}^{i=12} \left(L_i . f_i^{0.424} . Q_i^{0.848} \right)}{Q_t} \right)^{0.702}$$

Fig.2 Variation of global cost function, CT, with hypothetical hydraulic gradient

Results of the optimum diameters (excluding the pump cost)

The diameters obtained after ignoring the pump cost for each of equal and unequal diameters are shown in the following Table3.

Table 3: Results of the diameters when excluding the pump cost

Pipe Ref. No.	Length, (m)	Commercial optimized diameters, (mm)	
		N_{35} P.N.W	Sch (3)P.N.W
P2	179	296.6	296.6
P3	547	296.6	296.6
P4	281	296.6	296.6
P5	236.5	211.8	235.4
P6	254	188.2	211.8
P7	362.5	169.4	188.2
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P14	233.5	131.8	84.6
P15	235	103.6	103.6

On comparison basis, the results for optimal diameters and the corresponding global costs for N_{35} P.N.W and Sch (3) P.N.W using the derivative method when ignoring pump cost, Table3, are compared with those obtained including pump cost. Using the same procedure, the results are given in Table 4

Table 4: Comparison of global costs and savings for N_{35} P.N.W and Sch (3) P.N.W, excluding and including pump cost by derivative method

Pipe Ref. No.	Commercial optimized diameters, (mm) "including pump cost"		Commercial optimized diameters, (mm) "Excluding pump cost"	
	N_{35} P.N.W	Sch (3) P.N.W	N_{35} P.N.W	Sch (3) P.N.W
Pipe Cost, (LE)	979,125.4	977,429.2	971,806.93	972,225.15
Global Cost, (LE)	3,521,654.5	3,520,818.5	3,345,400.0	3,346,534.3

Pipe cost Saving % Compared with same P.N.W	-------	-------	0.75 %	0.535 %
Global cost Saving % Compared with same P.N.W	-------	-------	5 %	5%

Investigation of Table 4 shows that:

- The reduction in diameters when excluding pump cost is expected and logical, Fig.3
- When excluding the pump cost in the optimization process, the savings in pipe cost are negligible which means that, the reductions in diameters size are slight for both schemes.
- 3- For global costs, the savings are about 5% for both schemes. The cost saving is found smaller than the cost savings ranging from 7% to 11% reached without ignoring the pump cost, [4].

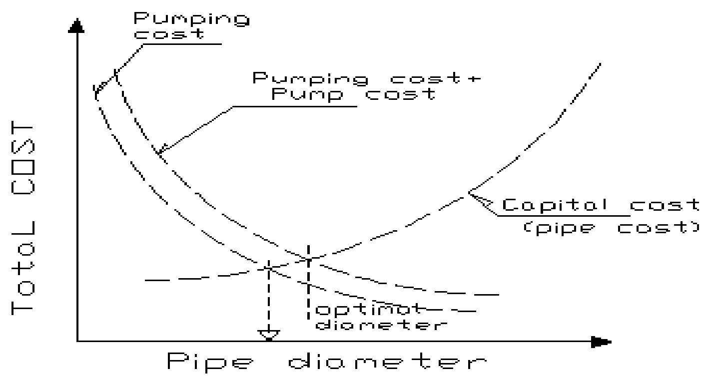

Fig.3. Effect of excluding pump cost on pipe diameters

5. Conclusion and Recommendations

5.1. Conclusions

From the present study the following remarks can be concluded:

1- The computer software is a basic step in the solution of pipe networks for discharge and friction head loss in individual pipes.
2- GANEO's Software (which runs for pipe cost only), verifies a cost saving in the pipe cost about 4.5% for N_{35} P.N.W and Sch (3) P.N.W, this is considered of minor importance.
3- For global costs, GANEO's solution gives costs much larger than these obtained by the derivative method. This is attributed to the smaller diameters reached by GANEO's solution which leads to larger operating head of pump and increase pumping and pump costs.
4- Although the GANEO's software leads to minimum diameters (minimum pipe cost) as an easier and quick method but the result must be treated with caution, since the energy and other costs are neglected.
5- The study assures the possibility of using the derivative method for global cost functions to develop analytical expression for optimal design of diameters of pipe networks.
6- Excluding pump cost could reduce the global costs, but this process is not recommended.
7- To improve the design diameters, all the cost parameters must be included in the optimization of the global cost functions to get the most reliable cost solution.

5.2. Recommendations

It is recommended to:

1- Apply the previous methodologies for the design and/or study of more complex pipe networks.

2- Apply the developed equation on actual water distribution systems, and use of more developed computer software to get optimal solutions with reduced time.

6. Symbols

A1 Unit cost of pumping
A2 Unit cost of pump

C	Cost coefficient of concrete elevated tank
C_1	Cost coefficient of labor and maintenance
C_2	Cost coefficient of treatment
C_3	Cost coefficient of inclusive
C_{et}	Cost of concrete elevated tank
C_{in}	Inclusive cost
C_L	Labor and maintenance cost
C_{p1}	Pumping cost
C_{p2}	Pump cost
C_{pi1}	Pipe cost of (main pipe- galvanized iron)
C_{pi2}	Pipe cost of (pipe network-Poly vinyl chloride-PVC)
D	Diameter of pipe
E.T	Elevated tank
f	Coefficient of friction
h_{fmax}	Max head lost by friction in the countered in the pipe network
h_{L1}	Friction and minor losses in the main from the well to the Elevated tank
h_{L2}	Friction and minor losses in the main from the elevated tank to the inlet of pipe network
h_r	Residual pressure head in the network
H_d	Operating pumping head
L	Length of the pipe
L_i	Individually pipe length
L_{sh}	Shortest flow line
P.N.W	Pipe network
Q_i	Individually pipe discharge
Q_t	Pumping flow rate
S	Optimum Hydraulic gradient
S_w	Drawdown in the well
T.W	Tested well
Z	Depth of water table before pumping from the ground level

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