Hydraulic calibration of water distribution networks based on ACO algorithms

Mehdi Dini[1], Massoud Tabesh[2],

1 PhD student, School of Civil Engineering, College of Engineering, University of Tehran, P. O. Box 11155-4563, Tehran, I. R. of Iran, Email: mehdini@gmail.com,

2 Professor, Center of Excellence for Engineering and Management of Civil Infrastructures, School of Civil Engineering, College of Engineering, University of Tehran, P. O. Box 11155-4563, Tehran, I. R. of Iran, Email: mtabesh@ut.ac.ir

ABSTRACT

The aim of this paper is to investigate a new method for hydraulic calibration of water distribution networks with nodal pressure and pipe flow sampling. In this regard an aggregate of an EPANET simulator model and an Ant Colony Optimization (ACO) algorithm has been used in a MATLAB setting. Generally in the ACO algorithm, the concentration of pheromone and heuristic factor was performed an important role in convergence of calibration model to the global optimal solution. In old models, the global optimal solution was reached with updating the pheromone using the best ant. In this paper, the objective function of the model specifically was defined that one part of it can be used to update the pheromone and the other part can be used to update the heuristic factor. So those together converged the model to the global optimal solution. The findings of this study showed that the new ACO algorithm method can lead to the global optimal solution with lesser evaluation than the old ACO algorithms.

Keywords: Hydraulic Calibration, Water distribution network, ACO algorithms, New method

1 INTRODUCTION

Various hydraulic simulation models are widely used nowadays by designers, water utilities, consultancy companies and many others involved in analysis, design, operation or maintenance of water distribution networks. In order to make a hydraulic model useful, it is necessary to calibrate it first (Walski, 1983). Calibration of pipe network models consists of determining the physical and operational characteristics of an existing system. This is achieved by determining various parameters that when are entered into a hydraulic simulation model, a reasonably good match between measured and predicted variables will be yield (Shamir and Howard, 1968).

Initial water distribution system (WDS) calibration methodologies were based on various trial and error procedures (Bhave, 1988; Rahal et al., 1980; Walski, 1983). Shortly after that, more systematic, explicit-type calibration approaches were introduced (Boulos and Wood, 1990;

Ormsbee and Wood, 1986). These approaches were soon replaced with “automatic,” optimization based calibration methodologies (Lansey and Basnet, 1991; Ormsbee, 1989). However, most (if not all) of the optimization-based WDS calibration approaches developed so far have focused primarily on the most computationally efficient and effective way of obtaining the optimal calibration parameter values. Researchers in this area have focused on water distribution hydraulic model calibration and a lot of objective functions are developed such as minimizing the difference between the field measured and the simulated values of nodal pressure, pipe flow and head of tanks with demand driven simulation method (DDSM) and head driven simulation method (HDSM) for hydraulic simulation of water distribution networks (Borzi et al., 2005; Yu et al., 2009; Tabesh et al., 2011). The objective of this paper is to introduce a new method of ACO algorithms for calibration of water distribution networks and comparing the results with other existing methods.

2 METHODOLOGY

For hydraulic and quality calibration of a water distribution network, an aggregate of an EPANET simulator model and an Ant Colony Optimization (ACO) algorithm has been used in a Matlab setting. ACO algorithms have been proposed by Dorigo et al. (1996). The probability function identified for this method is as eq. (1):

$$P_{ij}(k,t) = \frac{\left[T_{ij}(t)\right]^{\alpha}\left[U_{ij}(t)\right]^{\beta}}{\sum_{j=1}^{J}\left[T_{ij}(t)\right]^{\alpha}\left[U_{ij}(t)\right]^{\beta}} \tag{1}$$

in which $P_{ij}(k,t)$: the probability of the k-th ant in node i at stage t, to choose edge j; $T_{ij}(t)$: pheromone concentration of the route ij in the time period t; $U_{ij}(t)$: an heuristic value associated to the route ij; and α & β weight the relative influence of pheromone and heuristic information on the final probability, respectively. J is the number of routes selected by ant k when it is placed in i decision making point (the number of coefficients chosen for each pipe).

The general form of the pheromone update equation is as follows (Dorigo et al., 1996):

$$T_{ij}(t+1) = \rho\, T_{ij}(t) + \Delta\, T_{ij}(t) \tag{2}$$

In which ρ is the pheromone's evaporation coefficient; $T_{ij}(t)$ is ij route's pheromone concentration in the iteration t; $T_{ij}(t+1)$ is ij route's pheromone concentration in the iteration (t+1); and $\Delta\, T_{ij}(t)$ is ij route's surplus pheromone in the period t. In the previous ACO algorithms, the objective function of the calibration model was as eq. (3) or (4).

$$F = \sum_{j=1}^{N}\sum_{t=1}^{T}\left(PO_{tj} - PS_{tj}\right)^2 \tag{3}$$

$$F = \sum_{j=1}^{N}\sum_{t=1}^{T}((PO_{tj} - PS_{tj})^2 + \sum_{i=1}^{N}\sum_{t=1}^{T}((QO_{ti} - QS_{ti})^2 \tag{4}$$

in which N is the number of the network's sampling nodes and T is the total hours of sampling the network. PO_{tj} is the observed or measured pressure and PS_{tj} is calculated pressure at node j and time t, QO_{ti} is the observed or measured flow and QS_{ti} is the calculated flow at pipe i and time t and F is the amount of the objective function to be minimized.

This paper describes the development and application of an Ant Colony Optimization based algorithm for hydraulic calibration of water distribution networks with nodal pressure and pipe flow sampling. In the old method the best number of the objective functions of the model only was used to update the pheromone and the heuristic factor was considered as constant. In the new method, the objective function is defined in two parts that one part of it (eq. 5) minimizes the difference between the model predicted and the observed nodal pressure values that can be used to update the pheromone and the other part (eq. 6) minimizes the difference between the model-predicted and the field-observed pipe flow values that can be used to update the heuristic factor. The general form of the objective function of the new method is as follows:

$$F_1 = \sum_{j=1}^{N} \sum_{t=1}^{T} \left(PO_{tj} - PS_{tj}\right)^2 \tag{5}$$

$$F_2 = \sum_{i=1}^{N} \sum_{t=1}^{T} (\left(QO_{ti} - QS_{ti}\right)^2 \tag{6}$$

3 CASE STUDY

To evaluate the proposed method a two looped network (Alperovits & Shamir, 1977) has been utilized which is used as a research sample in different papers. The layout of the network is shown in Figure 1 and its general characteristics are demonstrated in Table 1. The consumption pattern of network is also shown in Table 2.

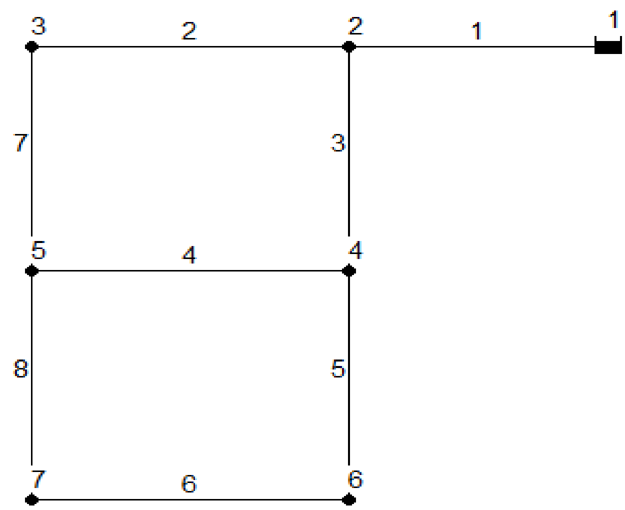

Figure 1. The two looped network with 8 pipes and 7 nodes (Alprovits and Shamir, 1977)

Table 1. Characteristics of nodes and pipes in the two looped network

Pipe Characteristics					Node Characteristics		
ID	Length (m)	Diameter (mm)	Roughness (C)	Wall decay (Kw)	ID	Elevation(m)	Demand(l/s)
1	1000	450	130	-0.1	1	210	0
2	1000	350	80	-0.6	2	150	27.8
3	1000	350	130	-0.1	3	160	27.8
4	1000	150	70	-0.7	4	155	33.4
5	1000	350	100	-0.4	5	150	75
6	1000	100	80	-0.6	6	165	91.7
7	1000	350	100	-0.4	7	160	55.6
8	1000	250	70	-0.7			

Table 2. Demand pattern in network's nodes at three consumption times

Consumption Time	Maximum	Average	Minimum
Demand Pattern	1.18	1	0.97

The hydraulic modeling of the two looped network was carried out by using EPANET. The nodal pressure and pipe flow at three consumption times are shown in Tables 3 and 4 which are considered as observation data when the roughness is unknown.

Table 3. Nodal pressure at three consumption times

Node ID	1	2	3	4	5	6	7
Maximum	0.00	51.43	25.40	39.37	28.40	23.76	3.04
Average	0.00	52.70	29.03	41.68	33.06	26.90	9.96
Minimum	0.00	55.17	36.14	46.19	42.18	33.03	23.52

Table 4. Pipe flow at three consumption times

Pipe ID	1	2	3	4	5	6	7	8
Maximum	339.32	151.20	157.82	14.22	107.19	7.24	120.90	53.37
Average	311.30	138.71	144.79	13.05	98.34	6.64	110.91	48.96
Minimum	249.04	110.97	115.83	10.44	78.67	5.31	88.73	39.17

The adjustable calibration model parameters including U_0, β, T0, α, ρ, $\Delta T_{i,j}(t)$ and N_{ant}: the number of ants in each step and N_{cyc}: the number of cycles in each step are resolved. The adjustment of the model parameters is carried out by using parameter sensitivity analysis and nodal pressure in sampling mode has been carried out in three nodes of 5, 6 and 7. In other words, considering that node pressure is known for the above nodes, model parameters are adjusted in a way that the model calibration can calculate the final answer in the most rapid and careful state. The results of sensitivity analysis are shown in Table 5 for old and new calibration model and they are used as the adjusted parameters in the final calibration model.

Table 5. Results of the calibration model parameters after sensitivity analysis

Parameter	Method	U0	ß	T0	α	ρ	$\Delta T_{i,j}(t)$	Ncyc	Nant
Value	Old	1	1	40	1	0.98	1	10	100
Value	New	40	1	40	1	0.98	1	10	100

4 RESULTS AND DISCUSSION

In this paper, the new approach of ACO algorithms for calibration of water distribution network was developed. The new method (NM) has two objective functions such as eqs. (5) and (6). To evaluate the results of the new method two other models were used. The objective function of model 1 (M1) is eq. (3) and the objective function of model 2 (M2) is eq. (4). To compare results of the above models, sampling is carried out in two nodes and in a network's maximum, average and minimum consumption times. Results are presented in Tables 6- 8.

Table 6. The number of objective function evaluation of NM with two nodes sampling

No	Max		Ave		Min	
	6,7	4,7	6,7	4,7	6,7	4,7
1	60000	25000	22000	36000	22000	33000
2	27000	37000	45000	25000	47000	23000
3	57000	33000	38000	30000	56000	35000
4	49000	38000	29000	38000	45000	22000
5	38000	35000	71000	29000	47000	45000
Ave	46200	33600	41000	31600	43400	31600
Ave	37900					

Table 7. The number of objective function evaluation of M1 with two nodes sampling

No	Max		Ave		Min	
	6,7	4,7	6,7	4,7	6,7	4,7
1	34000	54000	34000	52000	30000	52000
2	56000	37000	56000	39000	56000	39000
3	44000	52000	44000	54000	44000	54000
4	63000	24000	91000	22000	91000	22000
5	92000	34000	64000	34000	64000	34000
Ave	57800	40200	57800	40200	57000	40200
Ave	48867					

Table 8. The number of objective function evaluations of M2 with two nodes or two pipes sampling

No	Max		Ave		Min	
	6,7	4,7	6,7	4,7	6,7	4,7
1	36000	40000	36000	52000	36000	46000
2	63000	42000	67000	40000	68000	39000
3	64000	38000	47000	35000	46000	42000
4	20000	27000	47000	33000	33000	33000
5	57000	33000	66000	25000	46000	25000
Ave	48000	36000	52600	37000	45800	37000
Ave	42733					

As it can be seen in the results of Tables 6-8, the new calibration Model (NM) has achieved the actual solution in an average of 39700 evaluations and M1 and M2 have achieved the actual solution in an average of 48870 and 42733 evaluations, respectively. In this part, to indicate the new model's ability, the results are compared for more sampling points. The number of objective function evaluations for sampling more than two nodes and two pipes are shown in

Table 9. Figure 2 represents a comparison between the results of the new and old models for different number of samplings.

Table 9. The number of objective function evaluations for more than two nodes and two pipes

Sampling Model	2 nodes and pipes	3 nodes and pipes	4 nodes and pipes	5 nodes and pipes
New Model	37900	30867	30000	29400
Model 1	48867	41400	40333	38600
Model 2	42733	39800	37333	35333

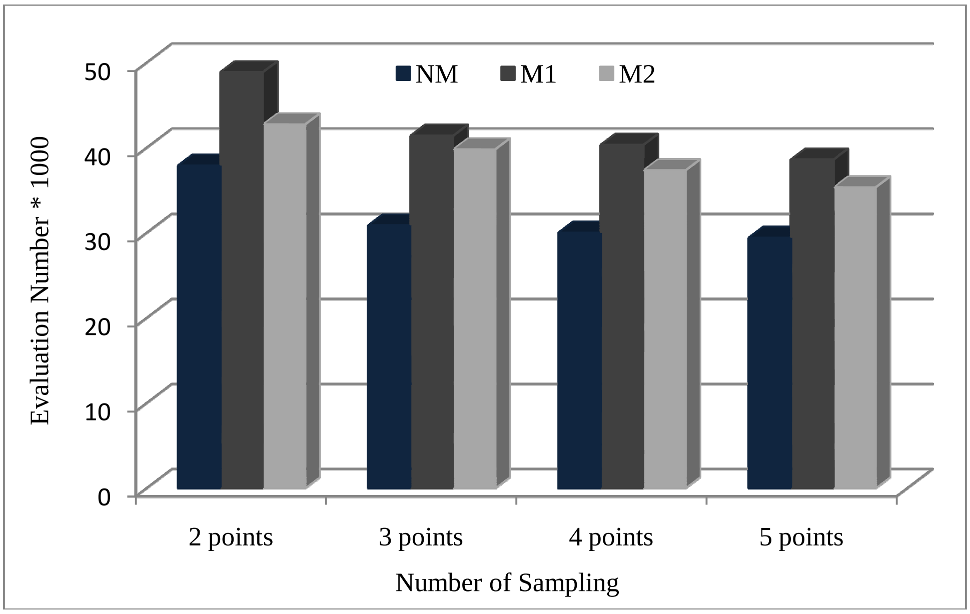

Figure 2. Comparison of new model results with two old models

It is illustrated in Table 9 that, in all conditions of sampling, the new model has achieved the actual solution in a lesser objective function evaluation. In Figure 2, the summation of results for new calibration model (NM) and two old calibration models (M1, M2) are presented. The findings of this study show that the new method is very successful for WDS hydraulic calibration.

5 CONCLUTIONS

The aim of this paper was to investigate hydraulic calibration of water distribution networks with the new ACO method. To do so, it used a two looped network that carried out the simulation by presupposing that roughness coefficients of pipes are known. The amounts of pressure and flow were estimated in network nodes and pipes to consider observational pressure and flow when the roughness is unknown. The hydraulic calibration model is an aggregate model of EPANET and Ant Colony optimization algorithm which has been supplied in MATLAB and its parameters were designed regarding a sensitivity analysis.

In the new method, two objective functions were defined. In one objective function, the difference between the model predicted and the observed nodal pressure values were minimized and the best one could be used to update the pheromone. In the other objective function the difference between the model-predicted and the field-observed pipe flow values was minimized and the best one could be used to update the heuristic factor. In the old method the best amount of the objective function only used to update the pheromone. Results showed that the new model has achieved the actual solution in a lesser objective function evaluation in comparison with the old models. For example, in state of five sampling points new model has achieved the actual solution in an average of 29400 evaluations and M1 and M2 have achieved the actual solution in an average of 38600 and 35333 evaluations, respectively.

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