Booster Chlorination Application Study for an Intermittent System of Supply Water Distribution Network

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Abstract - Regulating desired free residual chlorine within distribution network of intermittent system of water supply is of great importance in reducing harmful disinfection by products in the region near to source and providing minimum chlorine residuals at the nodes faraway from source. Booster chlorination application at in-between locations along with source chlorination of water distribution network during the simulation period decreases the difference between the chlorine residual measures at distinct nodes of water distribution network from the permissible range. Using EPANET-MATLAB-Toolkit, chlorine residuals are determined at different nodes of network. Total chlorine application rate in mass of intermittent system of water supply distribution network along with distribution of chlorine residuals among the nodes of network are studied with and without booster chlorination strategy in the present study which helps to improve effective management of chlorine.

Index Terms - Free residual chlorine, Booster chlorination, Intermittent system of water supply, EPANET-MATLAB-Toolkit

INTRODUCTION

Safeguarded and easily available drinking water is essential for public wellness. Because of rapid population growth, water is notified to be becoming more deficient all over the world. Inadequacy of drinking water, inferior infrastructure for water management approaches, torrents and shortage of rainfall and pollution of water bodies are the key issues of water in developing countries. Because of excessive usage of pesticides, insecticides and industrial and sewage discharges, ineffective superintendence of resources the quality of water is deteriorating rapidly. To ensure safe drinking water to a particular city or town, water treatment is necessary. Disinfection is the most significant treatment method to ensure safety in water distribution network system. Disinfectant residuals should be maintained to lower pathogenic contamination in distribution system water to be supplied. To control pathogens progression, chlorine is usually utilized disinfectant because it is safe, inexpensive and has the potential of keeping its residuals for prolong time to exclude subsequent contaminates in water distribution network (WDN). Pungent and unfavourable taste imparts to water because of unwanted application of chlorine and can originate to the evolution of disinfection by-products which are carcinogenic like trihalomethanes [1-3].

Water is supplied only for a particular period of time in intermittent system of water supply which is adopted in developing countries. At different junctions of WDN, free residual chlorine (FRC) decreases as a consequence of delivering water during fewer hours of a day or fewer days of a week. Consumers' illness is at greater level because of contamination of water pipelines during no supply hours [4-5]. To manage FRC concentrations throughout the network, modelling of chlorine decay in WDN is of great importance. Chlorine decay is affected by two different reaction approaches, the first involves reactions in the bulk flow and another involves reactions caused by pipe wall material [6]. To describe chlorine decay few of kinematic models are first order, second order and power law expressions models [7]. To express chorine decay of bulk and wall, first order decay kinetic model is currently often used [8]. Coefficient of wall decay is overlooked in several optimization researches [9-11]. In the current analysis, coefficient of bulk decay is only taken and it is adopted as 0.55day^{-1}, decay coefficient of wall is neglected [12].

In accordance with World Health Organization permitted limit for FRC is 0.2-0.5 mg/l [13]. For the sake of maintaining minimum FRC as 0.2mg/l at the farthest nodes of WDN, chlorine application rate in mass at source is to be increased [14]. But increased chlorine rate at source may cause odour and taste trouble by consumers experiencing the higher FRC at nodes close to source and far way nodes have lower FRC [15]. Keeping uniform FRC throughout the WDN is required [16-17]. Maintaining minimum FRC is troublesome in intermittent water supply as the moving pattern of chlorine which is applied to WDN is more compared to water supply duration [18-19]. In traditional method of disinfection, chlorine is applied at source of WDN only [20-21]. To maintain uniform FRC all over the WDN, disinfection alone at source is not adequate [22]. To keep FRC within permissible limit and uniform throughout WDN, booster chlorination is the suitable method. In this approach chlorine is introduced at selected nodes of WDN besides source [23].

EPANET, a public domain modelling software package is applied to accomplish simulation of water quality and hydraulic behaviour in the pressurized water distribution pipe networks [24]. To run extended period simulations for water quality and hydraulic modelling, EPANET-MATLAB-Toolkit is applied [25]. In this study, for extended period simulation, EPANET-

MATLAB- Toolkit is taken to analyse the scenarios performed for variations in FRC at different nodes of WDN with and without booster chlorination.

MATERIALS AND METHODS

A. Study Area

An intermittent system of water supply, Yellammabanda distribution network as shown in Figure 1 (Network 1), placed 20.2 kilometres northwest of Hyderabad in Telangana state, India is considered to examine the present study.

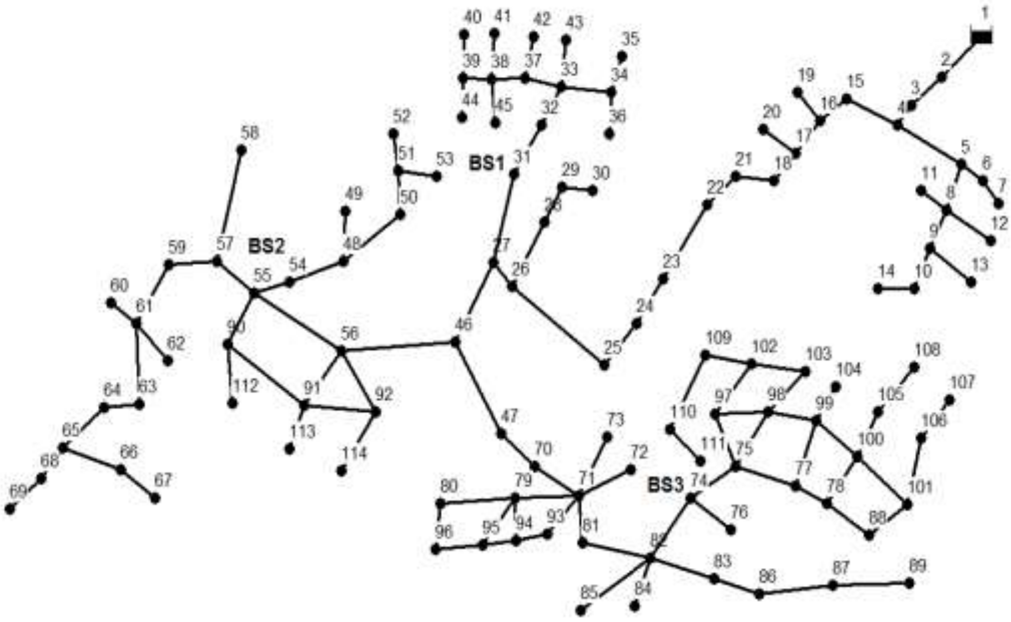

Figure 1. Design of Network 1

Network 1 is having 113 nodes, 123 pipes and overhead service reservoir which has capacity 26MG. Node details are given in Table 1. Node demand of Network 1 is determined by considering density of population and water supplied area of each node. Total length of pipelines of Network 1 is 72.3790 kilometres and diameter of different pipes of Network 1 varied from 100 mm to 1000 mm. Supply hours of Network 1 which is having an intermittent system of supply are 4a.m. to 10a.m. i.e. 6 hours for every alternative days. Total head of overhead service reservoir is 580 m. Nodes base demand of water varied from 36.52 lpm to 130.55 lpm.

Table 1. Node details of Network 1

Node ID	Demand (lpm)	Node ID	Demand (lpm)	Node ID	Demand (lpm)	Node ID	Demand (lpm)
2	83.3	32	110.23	62	125.45	92	115.87
3	57.32	33	89.96	63	126.89	93	127.45
4	66.32	34	114.74	64	98.44	94	129.56
5	82.31	35	102.84	65	124.22	95	122.85
6	68.96	36	109.85	66	130.55	96	117.65
7	82.36	37	113.56	67	126.2	97	125.22
8	78.66	38	104.89	68	124.62	98	118.66
9	57.6	39	107.23	69	100.5	99	119.55
10	54.45	40	120.89	70	106.85	100	112.85
11	77.63	41	96.63	71	122.25	101	123.42
12	58.62	42	84.36	72	115.62	102	118.25
13	36.52	43	104.55	73	126.55	103	114.36
14	46.58	44	103.85	74	119.88	104	113.57
15	74.8	45	122.56	75	116.56	105	114.85

16	75.56	46	75.85	76	102.46	106	115.55
17	95.51	47	93.63	77	108.55	107	113.82
18	86.63	48	85.54	78	113.22	108	102.77
19	78.96	49	107.89	79	126.78	109	108.52
20	84.75	50	111.55	80	117.63	110	122.22
21	92.77	51	110.23	81	122.55	111	109.85
22	69.84	52	123.56	82	117.56	112	114.75
23	95.55	53	124.11	83	121.44	113	85.56
24	100.56	54	115.45	84	121.77	114	75.25
25	96.68	55	103.33	85	123.72		
26	95.89	56	130.55	86	118.2		
27	112.23	57	128.36	87	116.65		
28	58.95	58	114.85	88	128.95		
29	95.86	59	111.88	89	126.85		
30	100.52	60	96.75	90	123.55		
31	104.89	61	123.63	91	128.88		

PROPOSED APPROACH

FRC at different nodes of Network 1 are determined using EPANET-MATLAB-Toolkit for the proposed scenarios. The total area of Network 1 is separated into three regions as RE1, RE2 and RE3 whereas RE1 is having nodes near to source, RE2 is having nodes at middle of Network 1 and RE3 is having nodes which are near to end of Network 1. Nodes in the regions RE1, RE2 and RE3 are given Table 2.

Table 2. Nodes in Regions RE1, RE2 and RE3

Region	Nodes of Network 1
RE1	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44 and 45
RE 2	25, 26, 27, 46, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 90, 91, 92, 112, 113 and 114
RE 3	47, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110 and 111

With the supply hours as 4a.m. to 10a.m. for alternative days are considered for a simulation period as six days to get FRC concentration at different nodes of regions RE1, RE2 and RE3. Average divergence of FRC at all nodes at all times of WDN from the range of 0.2-0.5 mg/l is calculated and it is called as ADIG [26]. ADIG will be zero if FRC concentration at different nodes of regions RE1, RE2 and RE3 during the simulation period is within the limit of 0.2-0.5 mg/l and ADIG is more than zero if FRC concentration at different nodes in regions RE1, RE2 and RE3 are not in equal and not in the limit of 0.2-0.5 mg/l.

To study the chlorination impact on FRC and ADIG in three regions RE1, RE2 and RE3 of Network 1, two scenarios are simulated. The first one is with chlorine application only at source whereas the second one is with chlorine application at source and booster stations. To maintain uniformity in FRC at the three regions of Network 1 and to decrease the value of ADIG, booster chlorination is applied at Node 31 (BS1) of region RE1, at Node 55 (BS2) of region RE2 and at Node 74 (BS3) of region RE3 and these are chosen depending on trial and error [14]. In the scenarios with and without booster chlorination, minimum, maximum and average values of FRC are analysed in the regions RE1, RE2 and RE3.

RESULTS AND DISCUSSION

For the two situations, simulation is performed.

In Scenario 1; chlorine application is only at supply source and in Scenario 2; chlorine application is at supply source and at booster stations BS1, BS2 and BS3 of the regions RE1, RE2 and RE3 sequentially. Total nodes in three regions RE1, RE2 and RE3 are 41, 32 and 40 sequentially.

In Scenario 1, for a period of 6 hours for every alternative day, chlorine application rate in mass at supply source is 16977.4848 g/day which is taken from present practice at WDN. For this supply duration, source injection rare is 47215.24 mg/min (1 mg/l). For regions RE1, RE2 and RE3, minimum, maximum and average FRC concentrations are represented in Figure 2, Figure 3 and Figure 4 sequentially.

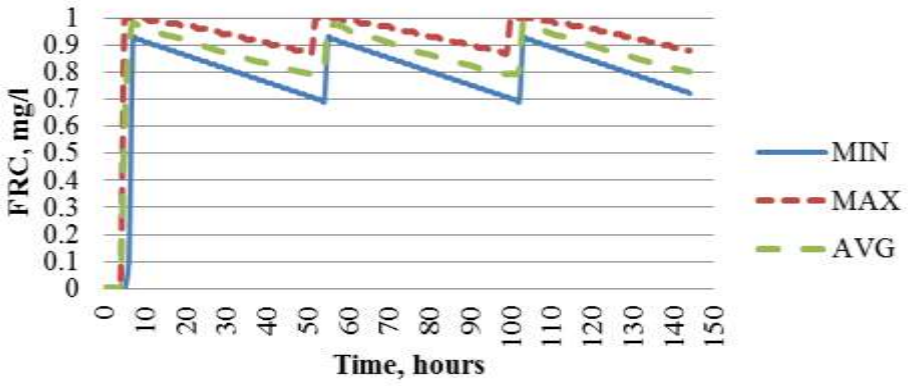

Figure 2. Minimum, maximum and average FRC concentrations in the region RE1 for Scenario 1 for last 48 hours of six days simulation period

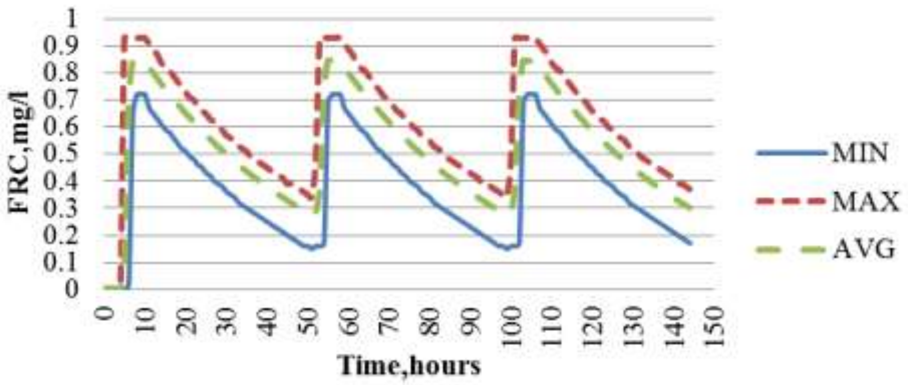

Figure 3. Minimum, maximum and average FRC concentrations in the region RE2 for Scenario 1 for last 48 hours of six days simulation period

In six days simulation period for last 48 hours, maximum FRC in the regions RE1, RE2 and RE3 are 1 mg/l, 0.93 mg/l and 0.86 mg/l sequentially; average FRC in the regions RE1, RE2 and RE3 are 0.7905 mg/l, 0.4937 mg/l and 0.3995 mg/l sequentially and minimum FRC in the regions RE1, RE2 and RE3 are 0.69 mg/l, 0.15mg/l and 0.06 mg/l sequentially.

The region RE1 is near to source of Network 1 and it is noticed that maximum, average and minimum FRC in that region remains on higher side because of conventional method of supplying high application rate of chlorine in mass at source.

Minimum FRC in the regions RE2 and RE3 is less than the minimum FRC to be maintained because these regions have the farthest nodes and there may be delay of getting chlorine concentration probably due to travel time. ADIG for the regions RE1, RE2 and RE3 are 0.3721, 0.1036 and 0.0750 sequentially. For the region RE1, ADIG is 0.3721 which is more than that of regions RE2 and RE3 because this region is having nodes whose FRC concentration is not in the limit of 0.2-0.5 mg/l during the simulation period.

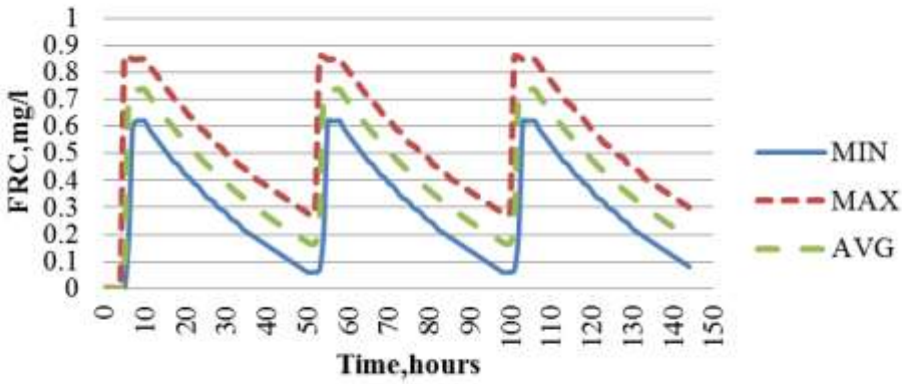

Figure 4. Minimum, maximum and average FRC concentrations in the region RE3 for Scenario 1 for last 48 hours of six days simulation period

To avoid higher FRC concentration in the region RE1 and to keep minimum FRC at the farthermost nodes of regions RE2 and RE3, implementation of booster chlorination for the Network 1 is required during the simulation period which is shown in Scenario 2.

Chlorine application rate in mass in Scenario 2 is 9550.2255 g/day which includes source chlorination at reservoir and booster chlorination at booster stations Node 31 (BS1) of region RE1, Node 55 (BS2) of region RE2 and Node 74 (BS3) of region RE3 of Network 1 for a period of 6 hours for every alternative day. Source injection rate is 25937.8243 mg/min (0.55 mg/l) and booster injection rate at booster stations BS1, BS2 and BS3 of regions RE1, RE2 and RE3 is 188.802 mg/min (0.3 mg/l), 185.994 mg/l (0.3 mg/l) and 215.784 mg/min (0.3 mg/l) sequentially. Figure 5, Figure 6 and Figure7 shows minimum, maximum and average FRC concentrations in the regions RE1, RE2 and RE3 sequentially.

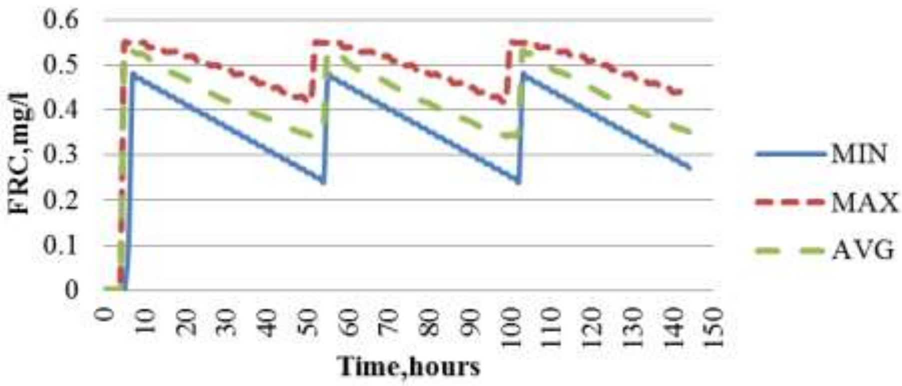

Figure 5. Minimum, maximum and average FRC concentrations in the region RE1 for Scenario 2 for last 48 hours of six days simulation period

For region RE1; minimum, maximum and average FRC concentrations are 0.24 mg/l, 0.55 mg/l and 0.3961 mg/l sequentially, for region RE2; minimum, maximum and average FRC concentrations are 0.24 mg/l, 0.58 mg/l and 0.3910 mg/l sequentially and for region RE3; minimum, maximum and average FRC concentrations are 0.21 mg/l, 0.55 mg/l and 0.3622 mg/l sequentially for last 48 hours of six days simulation period in Scenario 2. By observing the average and minimum FRC values in these regions, nodes in the region RE1 are not receiving higher FRC concentrations as like in Scenario 1 and farthest nodes in regions RE2 and RE3 are maintaining minimum FRC during the simulation period. This happened because of reducing chlorine application rate in mass at source and booster chlorination implementation at three nodes of these regions of Network 1 in Scenario 2.

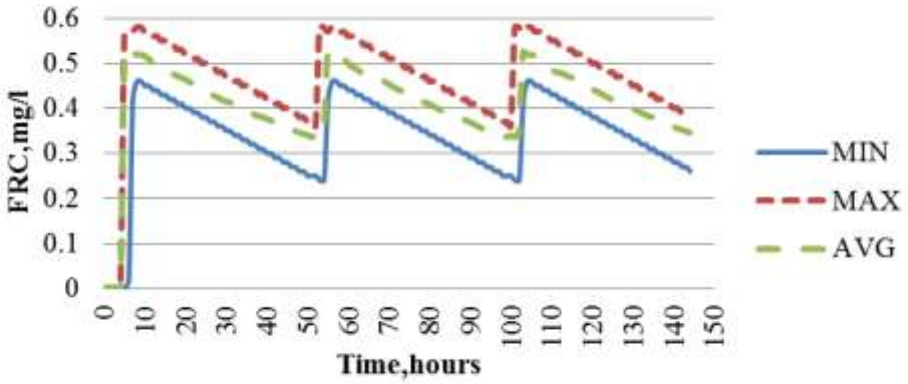

Figure 6. Minimum, maximum and average FRC concentrations in the region RE2 for Scenario 2 for last 48 hours of six days simulation period

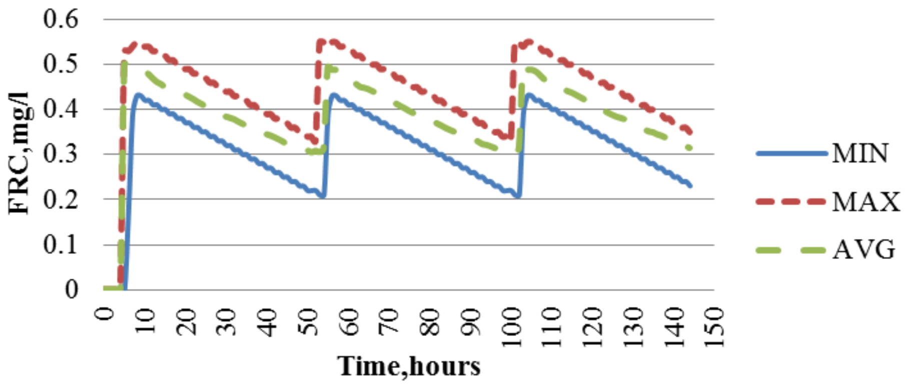

Figure 7. Minimum, maximum and average FRC concentrations in the region RE3 for Scenario 2 for last 48 hours of six days simulation period

For the regions RE1, RE2 and RE3, ADIG values are 0.0062, 0.0150 and 0.0100 sequentially for the simulation period of six days. When comparing these ADIG values with Scenario 1 ADIG values, scenario 2 ADIG values are reduced i.e. FRC concentrations at different nodes in the region RE1 are not in high levels and FRC concentrations of farthest nodes in the regions RE2 and RE3 are having desired FRC concentration during the simulation period.

Variations in ADIG values for regions RE1, RE2 and RE3 of Scenarios 1 and 2 are shown in Figure 8.

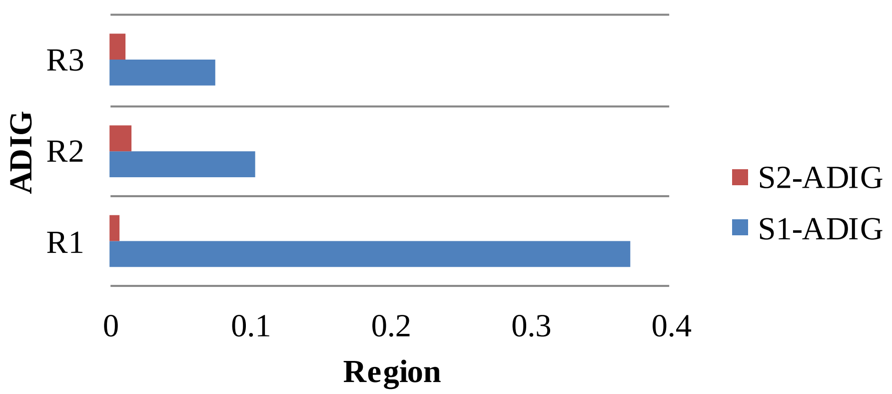

Figure 8. Variations in ADIG for regions RE1, RE2 and RE3 of Scenarios 1 and 2

Table 3 shows the details of Scenario 1 and 2 of chlorine application rate in mass and its injection rate at source and booster stations; Minimum, maximum and average FRC concentrations for the last 48 hours of simulation period in the three regions RE1, RE2 and RE3 of Network 1 and their ADIG values during the simulation period.

Table 3 Details of Scenarios 1 and 2 of Network 1

Total chlorine application rate in mass	**Chlorine application at source**	**Duration of chlorine application**	**Region**	**Chlorine application at booster station**	**MAX**	**MIN**	**AVG**	**ADIG**
g/day	mg/l	hours		mg/l	mg/l	mg/l	mg/l	
				Scenario, S1				
16977.4848	1(Source injection rate as 47215.24mg/min)	6	RE1	---	1	0.69	0.7905	0.3721
			RE2	---	0.93	0.15	0.4937	0.1036
			RE3	---	0.86	0.06	0.3995	0.0750
				Scenario, S2				
9550.2255	0.55(Source injection rate as 25937.8243 mg/min)	6	RE1	0.3 (Booster injection rate at BS1 as 188.802mg/min)	0.55	0.24	0.3961	0.0062
			RE2	0.3 Booster Injection rate at BS2 as 185.994mg/min)	0.58	0.24	0.3910	0.0150
			RE3	0.3 (Booster injection rate at BS3 as 215.784mg/min)	0.55	0.21	0.3622	0.0100

CONCLUSIONS

For efficient implementation of chlorine application, two approaches are considered for an existing water distribution network; one is chorine application at source only and the other one is chlorine application at both source and booster stations. Following are the results noticed from the run of extended period simulation of Network 1 for chlorine application strategies.

For conventional method of disinfection, chlorine application rate in mass at source is high which fails to keep minimum FRC concentrations at the farthermost nodes of regions and remains higher FRC concentrations at nodes near to source, results in harmful disinfectant by products.

With implementation of booster chlorination at some nodes besides source appliance, reduction of chlorine application rate in mass at source is noticed; thereby decrease in total chlorination application for Network 1.

With the execution of booster chlorination strategy as shown in Scenario 2, 43.8139% reduction in total mass rate of applied chlorine is acquired than the conventional method of chlorine application as shown in Scenario 1.

ADIG values of regions RE1, RE2 and RE3 are reduced in Scenario 2 compared to the values of Scenario 1 because of maintaining even distribution of chlorine at all locations of Network 1.

Because of booster chlorination application, reduction in ADIG is 90.1733% in Scenario 2 compared to Scenario 1.

By taking into consideration of field values of FRC at selected nodes of Network 1 during the simulation period, obtaining optimal location of booster stations and organizing of booster chlorination application will be the continuation of present study.

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