

Chapter 6

Summary and Conclusions

6.1 Summary

Significant water qualities changes within drinking water distribution systems (DWDS) makes it difficult for drinking water utilities to supply good quality water and to comply with regulatory requirements of maintaining a desired residual chlorine (0.2 mg/L as per IS 10500 – 2012) in DWDS. Therefore, it is very essential for water supply authority to manage the chlorine disinfection within lower and upper limit of residual chlorine to safeguard the consumers from water borne diseases and harmful disinfection by products (DBPs) simultaneously. The present research provides the tools and strategies by using advanced methods of water quality modelling and optimization methods for water quality management within DWDS with specific focus on management of chlorine disinfection. The water quality modelling is used for the simulation of residual chlorine, to check the effects of system of water supply, travelling time of chlorine and chlorine application strategy (i.e. conventional and booster chlorination) on residual chlorine concentration in DWDS. The simulation study reveals that the adopting booster chlorination strategy results in less chlorine mass rate application at the same time more suitable for uniform distribution of chlorine than the conventional method. The uniform distribution and reduction in application of chlorine mass rate results indirect benefit of reduction in harmful disinfection by-products (DBP). The optimization methods like linear programming and PSO are used to couple the water quality model for scheduling and managing optimum level of chlorine mass rate application for booster chlorination to manage residual chlorine within DWDS. Further the study is extended for the optimal location and selection of number of booster stations to check the effectiveness of booster chlorination approach and to justify its use for the crucial task of protecting water from microbial contamination. The development of impact matrix using impulse response coefficients for the rapid estimation of the effect of individual booster stations can guide decision makers for the trail strategy in the problematic area. The various decision support models developed in this research study can be used for the overall management of residual chlorine in DWDS and help in maintaining good quality water supplied to the consumers.

The following major conclusions are derived from the present study.

6.2 Conclusions

The main objective of the study is to adopt booster chlorination strategy for the uniform distribution of chlorine in distribution network. Various case studies are tested for different strategies for simulation models and optimization models. Following major conclusions are drawn from the results of both the models.

Important conclusions drawn from the Simulation Models:

1. Various Case studies show that the residual chlorine concentration depends on network configuration, flow hydraulics, travelling time of chlorine, water supply system, supply hours, zoning, and source / booster chlorine injection rate.
2. Residual chlorine concentration can be represented at various nodes using impulse response coefficient. Explicit equations in terms of flow and chlorine mass rate for quick computation of the residual chlorine concentration at various nodes are developed to decide the effect of booster chlorination on residual chlorine concentration. These linear equations can be further coupled with optimization technique for further use.
3. Case study 2 suggests that the zoning system of water supply is effective in managing the residual chlorine in intermittent water supply system. It is useful in maintaining the residual chlorine by reducing the travelling time of chlorine at the farthest node.
4. 24 X 7 water supply systems are better in managing the residual pressure and chlorine in DWDS than intermittent water supply as suggested from the results of case study 3.
5. Source chlorination can provide required residual chlorine in entire network however the distribution of the residual chlorine is uneven. For the uniform distribution of chlorine booster chlorination strategy is required. However, the provision of booster chlorination is only cost effective in such conditions where farthest nodes are not receiving minimum desired residual chlorine concentration due to greater travelling time than supply hours. (Case studies: 1,4,5)
6. Booster Chlorination provides effective chlorine management strategy by supplying uniform distribution of chlorine, minimizing cost and at the same time prevents the problems due to excess chlorination such as DBP.(Case studies : 1,4,5)
7. The simulation of residual chlorine also helps to find the critical locations for sample collection and sensor placement for the monitoring of chlorine in the drinking water distribution systems.

The important conclusions drawn from the Coupled Simulation Optimization Models:

1. Principle of linear superposition is successfully used for the development of optimization model to minimize the total mass rate of chlorine to be applied at multiple points in DWDS while satisfying the constraints of residual chlorine of 0.2 mg/L at all the locations.
2. The number of constraints can be reduced by selecting the few critical nodes in the network where minimum residual chlorine concentration is maintained as 0.2 mg/L. Selection of few critical nodes identified to compute the residual chlorine concentration at that location reduces the size of the problem.
3. The optimization results using linear programming (LP) for the optimum location of booster stations by taking up various combinations of booster stations shows that the scheduling of the mass rate of chlorine gives considerable reduction in the total mass rate of chlorine (29 – 34%) as compared to conventional chlorination at source alone. This reduction helps in savings of chlorine and also helps in reducing harmful DBP. Booster chlorination also results in uniform distribution of chlorine concentration as compared to source chlorination. (Case study: 6, 7, 8 and 10)
4. For the small distribution network, the travelling time of chlorine is normally less than supply hours. In such cases booster chlorination is not much cost effective. As the supply hours increases the reduction in the total mass rate of chlorine injection decreases. This condition suggests that the booster chlorination can only be justified when the travelling time to the farthest nodes is less than the supply hours. (Case study: 9)
5. The optimal location of booster stations, the coupled simulation optimization model using LP needs trial and error process or many combinations need to be evaluated. Such approach is tedious and time consuming.
6. PSO model is developed to find optimum chlorine injection for specified booster locations. The results of PSO model shows good agreement with that obtained by LP model. (Case study 11)
7. PSO is further extended for optimal location as well as scheduling of chlorine injection. The model produced the desired results without any trial and errors. The coupled simulation optimization model using PSO is found versatile compared to LP models. (Case study: 12, 13, 14)
8. Penalty functions are successfully used to convert the constraints into unconstrained problem suitable for PSO application.

9. The results show that LP and PSO are giving similar results for the optimal location and scheduling of mass rate of chlorine at source and booster stations. Booster chlorination stations suggested by coupled simulation optimization model results in better uniformity of residual chlorine as compared to conventional chlorination.
10. The values of impulse response coefficients are also used to generate impact matrix which is useful for the quick decision regarding the problematic area. Impact matrix for booster chlorination can help decision maker for management of residual chlorine in the network by suggesting the impact of a single booster dose on the critical/selected node.
11. The cost analysis of booster stations shows that the chlorine solution cost is the major cost in operating the booster stations. Hence the objective function selected to minimize the mass rate of chlorine is justified to provide the economical solution for the installation of booster station.
12. For complex problem having nonlinear objective function, PSO for optimal location and optimization of chlorine mass rate serve as an important decision support models (DSM) for managing, scheduling and selection of number and location of booster chlorination stations for drinking water distribution system (DWDS).

The development of various decision support models can be effectively used for the overall management of chlorine disinfection in any DWDS and can safeguard the consumers against microbial contamination and DBP formation by managing the residual chlorine within safe limit as per (IS 10500-2012).

6.3 Research Contributions

Following major contributions can be attributed to the present research work by development of various decision support models as mentioned following:

1. Development of explicit equations for the hydraulic and water quality simulation for the simple branch network which can be easily coupled with optimization method and useful to evaluate the booster chlorination strategy.
2. Evolving strategies for optimal location and scheduling of mass rate of chlorine to minimize the dose of chlorine to be applied at booster stations and source. This will result in more uniform distribution of chlorine and reduction of the cost of chlorine at the same time safeguard the consumers from the harmful effects of excess chlorination.
3. Development of impact matrix for booster chlorination for rapid conclusions regarding problematic area and guide regarding the selection of booster chlorination strategies. This will guide the water supply authority regarding the selection of monitoring sites for chlorine and problematic area for sensor placement and monitoring of residual chlorine concentration in DWDS.

The various decision support models (DSM) developed in this research study will provide improved tools for decision support system to the water supply managers for the crucial task to maintain balance between lower and upper limits of residual chlorine and DBP formation by managing sufficient level of residual chlorine in treated water by applying booster chlorination strategies. Thus, it will help to safeguard water supplied to the consumers against microbiological recontamination in the drinking water distribution system (DWDS) and ultimate benefits to the consumers by supplying safe drinking water and protection against various waterborne diseases and harmful effects of DBP formation due to excess chlorination.

6.4 Scope for Further Research Work

Following extension of the present research study is possible.

1. Simulation model can be improved by taking more field measurements of bulk decay coefficient.
2. Further study can be carried out to simulate the disinfection by-product such as total trihalomethanes (TTHM) for DWDS.
3. Study can be extended to identify the identification of source of contamination in DWDS.