Enhancement of the free residual chlorine concentration at the ends of the water supply network: Case study of Souk Ahras city – Algeria

Mohamed A. BENSOLTANE1, 2) ABD, Lotfi ZEGHADNIA2) ACE, Lakhdar DJEMILI1) EF, Abdalhak GHEID2) CD, Yassine DJEBBAR3) AD

1) Badji Mokhtar Annaba University, Faculty of Science Engineering, Department of Hydraulic, Annaba, Algeria; e-mail: bensoltaneamine84@gmail.com
2) University of Souk Ahras, Laboratory of Sciences and Technical in Water and Environment, 41000 Souk Ahras, Algeria; e-mail: zeghadnia_lotfi@yahoo.fr
3) University of Souk Ahras, Faculty of Sciences and Technology, Department of Civil Engineering, Souk Ahras, Algeria

For citation: Bensoltane M.A., Zeghadnia L., Djemili L., Gheid A., Djebbar Y. 2018. Enhancement of the free residual chlorine concentration at the ends of the water supply network: Case study of Souk Ahras city – Algeria. Journal of Water and Land Development. No. 38 p. 3–9. DOI: 10.2478/jwld-2018-0036.

Abstract

The drinking-water supply sector has mostly targeted the water-borne transmission of pathogens. The most common method employed is the chlorination of drinking-water at treatment plants and in the distribution systems. In Algeria, the use of chlorine in drinking water treatment is a widespread practice. To enhance the concentration of the residual chlorine in the public water-supply system of a part of Souk Ahras city (Faubourg) (Algeria) known by its low concentration of the free residual chlorine (according to the water utility – Algérienne des Eaux: ADE investigation) especially at the point of use, practical steps were carried out. The method is a combination between numerical simulation using EPANET2 software and field measurements. Using statistical analysis the hydraulic model was calibrated and the observed values were very closer to the simulated results. The concentration was improved throughout the network after the injection of the appropriate dose.

Key words: Algeria, drinking water, EPANET2, residual chlorine decay, Souk Ahras city, water supply network

INTRODUCTION

All people, whatever their stage of development and their social and economic conditions, have the right to have access to an adequate supply of safe drinking water [WHO 2003]. Disease statistics are stark and tragic: 80% of illness and death in the developing world is water-related; half of the world’s hospital beds are occupied by people with water-related diseases; diarrhea and malaria are by far the largest causes of mortality in children <5 years of age (34%) in Africa; and the number of deaths from water-related disease approaches 5 million annually, most of them children. These deaths, most of which are preventable, largely occur among the estimated 1.2 billion people worldwide [BATTERMAN et al. 2009; WHO 2005].

The main goal of treatment of drinking water is produce water that meet national and WHO standards [BOUSLAH et al. 2017; Quebec government 2002]. Disinfection of water helps, in fact, significantly reduces pathogenic microorganisms that are responsible for water-borne diseases such as typhoid fever, hepatitis, cholera, bacillary dysentery [CRITTENDEN et al. 2005].
CAIRNCROSS et al. [1996] suggest that a distinction should also be made between transmissions in two different physical domains: the public domain (outside the household) and the domestic domain (inside the household). A desired health benefit would only be obtained if transmission of pathogens in both the domains is prevented [PETER et al. 2003]. Most water-supply systems in the developing countries are not working according to design, which likely allow the entrance of wastewater. The drinking-water supply sector has mostly targeted the water-borne transmission of pathogens. The water should be protected against the possible pollutions by using disinfectant residual. Disinfectant residual should be maintained in the distribution system to protect it from recontamination.

Chlorine is used worldwide as a disinfectant residual to counteract microbial contamination and proliferation in drinking water supply systems (at treatment plants and in the distribution systems) [DHIAIUA-DI et al. 2015; GALAL 1996; NILUFAR et al. 2016; 2017]. Chlorine’s residual potential not only prevents potential regrowth of microorganisms throughout water distribution systems, but also provides subsidiary protection against pathogen intrusion [KIM et al. 2014; WHITE 1992]. Its popularity arises from its high oxidation potential, relatively low cost, high disinfection efficiency, and ease of use.

Several studies have focused on chlorine decay and factors affecting wall decay, such as the pipe material, flow velocity, water quality, and service age of the pipe [AL-JASSER 2007; AL-OMARI, CHAUDHRY 2001; DIGIANO, ZHANG 2005; FISHER et al. 2011a, b; HALLAM et al. 2002; ISABEL et al. 2000; MONTEIRO et al. 2017; RAMOS et al. 2010; VASCONCELOS et al. 1995] and so on.

This paper aims to propose a method to improve and keep the concentration of the free residual chlorine at the ends of the water distribution network at 0.3 mg·dm⁻³ or greater [POWELL et al. 2000; RODRIGUEZ, SERODES 2001]. Most individuals are able to taste chlorine or its by-products (e.g. chloramines) at concentrations below 5 mg·dm⁻³, and some at levels as low as 0.3 mg·dm⁻³ [WHO 2003]. The method is a combination between numerical simulation where the analysis software used was EPANET2 [ROSSMAN 2000], and field measurements. Series of sampling through the network were done to assess the free chlorine concentration in different points. The proper solution for the best concentration of the free residual chlorine throughout the network and especially at the ends was proposed.

**METHODS**

**STUDY AREA**

The case study was carried out in urban neighborhood – Faubourg – it lies in Souk-Ahras, North-East of Algeria as shown the Figure 1. The area is supplied from two tanks with a capacity of 400 m³ each. It is an old urban area that has reached saturation. This area is small; it includes 398 domestic subscribers, 15 government buildings and 34 small businesses. The network is of 4.5 km long, it consists mainly of PVC, pipe diameter range from 63 to 160 mm.

**DATA COLLECTION FOR HYDRAULIC MODEL**

The analysis software used was EPANET2 [ROSSMAN 2000], a program that models water flow including mixing and separating of water flows in water distribution pipeline network and provides time series data analysis. Reactions can occur both within bulk flow and with pipe wall.

**BULK REACTIONS**

EPANET can models the reactions in the body of water with kinetics of order $n$. Which means that the instantaneous rate of reaction $R$ (in units of mass/volume/time) depends on the concentration according to the formula:

$$R = k [C]^n$$
Where:  

\[ R = K_b C^n \]  

(1)

Where: \( K_b \) = the reaction constant (concentration raised to the power of \((1 - n)\) divided by time), \( C \) = the reactant concentration (mass/volume).

It is positive for growth reactions and negative for decay reactions:

\[ R = K_b (C_l - C) C^{(n-1)} \]  

(2)

EPANET can also consider reaction where a limiting concentration exists on the ultimate growth or loss of the substance. In this case the rate expression for growth reaction becomes:

\[ R = K_b (C_l - C) C^{(n-1)}, \ n > 0, \ K_b > 0 \]  

(3)

\[ R = K_b (C_l - C) C^{(n-1)}, \ n > 0, \ K_b < 0 \]  

(4)

Where: \( C_l \) = the limiting concentration.

The three parameters (\( C, K_b \) and \( C_l \)) are used to characterize the bulk reaction rate.

**WALL REACTIONS**

The rate of the reaction occurred near the pipe wall can be considered to be dependent of the concentration of the bulk flow, using the following expression:

\[ R = (A/V)K_w C^n \]  

(5)

The first factor is represented by a mass transfer coefficient which depends on the molecular diffusivity of the traced substance. Chlorine diffusivity is equal to \( 1.44 \times 10^{-5} \text{ cm}^2 \text{ s}^{-1} \) in water at 25°C, where \( R \) is the rate of reaction (mass/volume/time), \( A/V \) is the surface area per unit volume within the pipe which equals \( 4/\text{pipe diameter} \), \( C \) is the chlorine concentration (mass/volume), \( n \) is the kinetics order = 0 or 1, and \( K_w \) is the wall reaction rate coefficient (length/time for \( n = 1 \) and mass/area/time for \( n = 0 \)).

The EPANET is automatically adjusting, to account for mass transfer between the bulk flow and the wall, basing on the molecular diffusivity of reactant under study and the Reynolds number of the flow. In case of zero-order kinetics, which is recommended by the program manuals, the wall reaction rate cannot be greater than the mass transfer rate, resulting in Equation (6):

\[ R = MIN (k_w, k_f C) (2/(D/2)) \]  

(6)

Where: \( R \) = the rate of reaction (mass/volume/time), \( k_w \) = the wall reaction rate constant (mass/area/time), \( k_f \) = the mass transfer coefficient (length/time), \( C \) = the chlorine concentration (mass/volume), \( D \) = the pipe diameter, MIN – minimum value.

A hydraulic model analysis has to be performed previously in order to provide the resulting flow distribution to the water quality module to transport the chlorine through the system.
Table 1. Calibration statistics for flow (n = 24)

| Specification          | Mean flow | Standard deviation | Standard error of the mean |
|------------------------|-----------|--------------------|---------------------------|
| Observed               | 20.32     | 2.241              | 0.458                     |
| Computed (EPANET)      | 21.74     | 2.943              | 0.601                     |
| Root mean square error |           | 0.301              |                           |
| Correlation coefficient|           | 0.974              |                           |

Source: own study.

RESULTS AND DISCUSSION

CHLORINE DECAY MODEL

Many efforts have been made in the last decades, the modeling of chlorine residuals is still complex, as it relies on the accuracy of hydraulic models to describe flows and flow velocities [ROSSMAN et al. 1994; SHANG et al. 2008].

Generally, the simulation tools of water quality impose a model for chlorine decay using first or second order model even EPANET [AL-JASSER 2007; FISHER et al. 2017; HAESTAD et al. 2003; NAGATANI et al. 2008; NAGWAN et al. 2013; OZDEMIR, UCAY 2002; VIEIRA et al. 2004]. For the chlorine bulk decay model, commonly the first order reaction is used [VASCONCELOS et al. 1997]; while several studies have demonstrated that a second order reaction can provide a more accurate prediction of chlorine concentrations [BOCCELLI et al. 2003; CLARK 1998; FISHER et al. 2012; SPEIGHT et al. 2009]. For EPANET a trial-error process was used to find the values for the best possible correlation. These are respectively 0.02 dm$^3 \cdot h^{-1}$ for $K_b$ (the bulk decay rate coefficient) and 0.003 dm$^3 \cdot h^{-1}$ for $K_w$ (the wall reaction rate coefficient), this later is at least 10 times lower than the values found in the literature, where POWELL et al. [2000] found that the $K_b$ value ranged from 0.02 to 0.74 dm$^3 \cdot h^{-1}$, whereas HALLAM et al. [2002] showed that the value of $K_w$ usually varies between 0 and 1.56 dm$^3 \cdot h^{-1}$ in practice cases, this can be explain by the materials types of the pipes where the most theme are in PVC (for a new pipes in PVC the values of $K_w$ is negligible [POWELL et al. 2004]).

CHLORINE MODEL CALIBRATION AND VALIDATION

According to the statistics of Table 1 and the results presented in the Figures 4 and 5, the hydraulic model is calibrated.
From the Figure 6 it is noteworthy that the measured values are close to the values simulated by the EPANET model, we can draw that the model is well calibrated for free residual chlorine. The gradually decrease of the chlorine along its path means that there is a consumption of the chlorine in the network (reaction between chlorine and natural organic matter (NOM) – bulk decay).

CHLORINE DECAY AT THE END OF NETWORK

After the calibration of the hydraulic and water quality models, EPANET enable to simulate and by the way to enhance the weak points of residual chlorine concentration through the network. An amount of 0.7 mg·dm$^{-3}$ was injected in the water tank, the simulation tool provide the following result: 9 points with low concentration in residual chlorine (<0.3 mg·dm$^{-3}$) were identified at the ends of the network, in order to achieve the proper concentration of the residual chlorine in these weak points, a dose of 1 mg·dm$^{-3}$ was added to the reservoir, the results were reported in the Figure 7.

As shown the Figure 7, the situation is match better than the precedent one, where the overall of the network ends have an appropriate concentration of residual chlorine, except one (1) point where the concentration is closer to 0.3 mg·dm$^{-3}$ (= 0.29 mg·dm$^{-3}$).

CONCLUSIONS

The concentration of the free residual chlorine at the beginning of water distribution network is higher than that in the rest of the network. An efficient method was proposed for the enhancement of the residual chlorine concentration in the water supply network, especially at the ends points of use. Numerical tool combined with field measurements were used. Based on statistics evaluation the model was calibrated and the simulation tool became enable to predict the behaviour of the chlorine decay in the network. The concentration was matched throughout the network after the injection of the appropriate dose (1 mg·dm$^{-3}$ instead 0.7 mg·dm$^{-3}$). Updates of the numerical tool are of capital importance, a several parameters could be changed during time like the roughness and flow loses.
REFERENCES

AL-JASSER A.O. 2007. Chlorine decay in drinking-water transmission and distribution systems: Pipe service age effect. Water Research. Vol. 41. No. 2 p. 387–396.

AL-Omari A.S., CHAUDHRY M.H. 2001. Unsteady-state inverse chlorine modeling in pipe networks. Journal of Hydraulic Engineering. Vol. 127. Iss. 8 p. 669–677.

Batterman S., Eisenberg J., Hardin R., Kruk M.E., Lemos M.C., Michalak A.M., Mukherjee B., Renne E., Stein H., Watkins C., Wilson M.L. 2009. Sustainable control of water-related infectious diseases: A review and proposal for interdisciplinary health-based systems research. Environmental Health Perspectives. Vol. 117. No. 7 p. 1023–1032.

Boccelli D.L., Tryby M.E., Uber J.G., Summers R.S. 2003. A reactive species model for chlorine decay and THM formation under rechlorination conditions. Water Research. Vol. 37. No. 11 p. 2654–2666.

Bouslah S., Djemili L., Houichi L. 2017. Water quality index assessment of Koudiat Medouar Reservoir, north-east Algeria using weighted arithmetic index method. Journal of Water and Land Development. No. 35 pp. 221–228. DOI 10.1515/jwld-2017-0087.

Cairncross S., Blumenthal U., Kolsky P., Moraes L., Tayeh A. 1996. The public and domestic domains in the transmission of disease. Tropical Medicine and International Health. Vol. 1. No. 1 p. 27–34.

Clark R.M. 1998. Chlorine demand and THM formation kinetics: A second-order model. Journal of Environmental Engineering. Vol. 124. No. 1 p. 16–24.

Crittenden J., Trussel R., Hand D., Howe K., Tchobanoglous G. 2005. Water treatment principles and design. 2nd ed. John Wiley & Sons Inc. ISBN 0471110183 pp. 1968.

Dhaouadi M., Zerdoumi R., Rebbani N., Gheid A. 2015. The relationship between chlorine consumption and trihalomethane formation from hydrophobic and trisphilic fractions: a comparative study between two dams of east Algeria. Journal of Water Reuse and Desalination. Vol. 5. Iss. 1 p. 72–82.

Digiano F.A., Zhang W.D. 2005. Pipe section reactor to evaluate chlorine-wall reaction. Journal of American Water Works Association. Vol. 97. No. 1 p. 74–85.

Fisher I., George K., Arumugam S. 2017. New model of chlorine-wall reaction for simulating chlorine concentration in drinking water distribution systems. Water Research. Vol. 125. No. 15 p. 427–437.

Fisher I., Kastl G., Sathiasivan A. 2012. A suitable model of combined effect of temperature and initial condition on chlorine bulk decay in water distribution systems. Water Research. Vol. 46. No. 10 p. 3293–3303.

Fisher I., Kastl G., Sathiasivan A. 2011a. Evaluation of suitable chlorine bulk-decay models for water distribution systems. Water Research. Vol. 45. No. 16 p. 4896–4908.

Fisher I., Kastl G., Sathiasivan A., Jegatheesan V. 2011b. Suitability of chlorine bulk decay models for planning and management of water distribution systems. Critical Reviews in Environmental Science and Technology. Vol. 41. Iss. 20 p. 1843–1882.

Galal G.H. 1996. Chlorine in water disinfection. Pure and Applied Chemistry. Vol. 68. No. 9 p. 1731–1735.

Haestad M., Walski T.M., Chase D.V., Savic D.A., Grayman W., Beckwith S. 2003. Advanced water distribution modeling and management. 1st ed. Waterbury, CT USA. Haestad Press. ISBN 0971414122 pp. 800.

Hallam N.B., West J.R., Forster C.F., Powell J.C. Spencer I. 2002. The decay of chlorine associated with the pipe wall in water distribution systems. Water Research. Vol. 36. No. 14 p. 3479–3488.

Isabel R.S., Solarik G., Koechling M.T., Anzek M.H., Summers R.S. 2000. Modeling chlorine decay in treated waters. Proceeding of the American Water Works Association and Water Quality Technology Conference, Denver, CO, USA, June 11–15th p. 1215–1229.

Kim H., Kim S., Koo J. 2014. Prediction of chlorine concentration in various hydraulic conditions for a pilot scale water distribution system. Procedia Engineering. Vol. 70 p. 934–942.

Monteiro L., Figueiredo D., Covas D., Menaia J. 2017. Integrating water temperature in chlorine decay modeling: a case study. Urban Water. Vol. 11. No. 10 p. 1097–1101.

Monteiro L., Figueiredo D., Dias S., Freitas R., Covas D., Menaia J., Coelho S.T. 2014. Modeling of chlorine decay in drinking water supply systems using EPANET MSX. Procedia Engineering. Vol. 70 p. 1192–1202.

Nagatani T., Yasuhara K., Murata K., Takeda M., Nakamura T., Fuchigami T. 2008. Residual chlorine decay simulation in water distribution system. The 7th International Symposium on Water Supply Technology. Yokohama, Japan. 22–24.11.2008 p. 1–11.

Nagwan G.M., Minerva E.M., Hisham A.H. 2013. Simulation of chlorine decay in water distribution networks using EPANET – Case study. Civil and Environmental Research. Vol. 3. No. 13 p. 100–116.

Nifurak L., Rehan S., Manuel J. R., Christelle L. 2016. Assessment of water quality in distribution networks through the lens of disinfection by-product rules. Water SA. Vol. 42. No. 2 p. 337–349.

Nifurak L., Manuel J.R., Farahat A., Rehan S. 2017. Minimizing the impacts of contaminant intrusion in small water distribution networks through booster chlorination optimization. Stochastic Environmental Research and Risk Assessment. Vol. 31. No. 7 p. 1759–1775.

Ozdemir O.N., Ucak A. 2002. Simulation of chlorine decay in drinking-water distribution systems. Journal of Environmental Engineering. Vol. 128. No. 1 p. 31–39.

Peter K.J., Jeroen H.J. E., Gayathri J., Wim V. D.H., Sandy C., Anders D. 2003. Effect of chlorination of drinking-water on water quality and childhood diarrhoea in a village in Pakistan. Journal of Health, Population and Nutrition. Vol. 21. No. 1 p. 26–31.

Powell J.C., Clement J., Brandt M. 2004. Predictive models for water quality in distribution systems. London, UK. IWA publishing, Alliance House. ISBN 184339913X pp. 106.

Powell J.C., Hallam N.B., West J.R., Forster C.F., Simms J. 2000. Factors which control bulk chlorine decay rates. Water Research. Vol. 34. No. 1 p. 117–126.

Quebec government. 2002. Guidelines for drinking water quality. Quebec. Ministry of Sustainable Development and Parks p. 45–71.

Ramos H., Loureiro D., Lopes A., Fernandes C., Covas D., Reis L.F., Cunha M.C. 2010. Evaluation of chlorine decay in drinking water systems for different flow conditions: From theory to practice. Water Resources Management. Vol. 24. No. 4 p. 815–834.

Rodriguez M.J., Serodio J.B. 2001. Spatial and temporal evolution of trihalomethanes in three water distribution systems. Water Research. Vol. 35. No. 6 p. 1572–1586.
Enhancement of the free residual chlorine concentration at the ends of the water supply network...

ROSSMAN L.A. 2000. EPANET2 Users Manual. EPA-600/R-00/057. Cincinnati, USA. USEPA National Risk Management Research Laboratory.

ROSSMAN L.A., CLARK R.M., GRAYMAN W.M. 1994. Modeling chlorine residuals in drinking-water distribution systems. Journal of Environmental Engineering. Vol. 120 p. 803–820.

SHANG F., UBER J.G., ROSSMAN L.A. 2008. Modeling Reaction and Transport of Multiple Species in Water Distribution Systems. Environmental Science and Technology. Vol. 42 p. 808–814.

SPEIGHT V., UBER J., GRAYMAN W., MARTEL K., FRIEDMAN M., SINGER P., DiGIANNO F.A. 2009. Probabilistic modeling framework for assessing water quality sampling programs. Denver, Colorado, USA. Water Research Foundation.

VASCONCELOS J.J., ROSSMAN L.A., GRAYMAN W.M., BOULOS P.F., CLARK R.M. 1997. Kinetics of chlorine decay. Journal American Water Works Association. Vol. 89. No. 7 p. 54–65.

VASCONCELOS J.J., TARAS F.B., ROSSMAN L.A., GRAYMAN W.M., CLARK R.M., GOODRICH J.A. 1995. Characterizing and modeling chlorine decay in distribution systems.

VIEIRA P., COELHO S.T., LOUREIRO D. 2004. Accounting for the influence of initial chlorine concentration, TOC, iron and temperature when modeling chlorine decay in water supply. Journal of Water Supply: Research and Technology-AQUA. Vol. 53. No. 7 p. 453–467.

WHITE G.C. 1992. Handbook of chlorination and alternative disinfectants. 3rd ed. Toronto. Canada. Van Nostrand Reinhold. ISBN 0442006934 pp. 1308.

WHO 2003. Background document for development of WHO guidelines for drinking-water quality. Geneva. World Health Organization. ISBN 92-4-156243-9 pp. 178.

WHO 2005. Guidelines for laboratory and field testing of mosquito larvicides. WHO communicable disease control, prevention and eradication. WHO pesticide evaluation scheme pp. 39.

YANG J., BEDUHN S., SWAILES D. 2007. IDSE and beyond: Application of computer modeling to distribution system water quality. Journal American Water Works Association. Vol. 99. No. 7 p. 76–82.

Mohamed A. BENSOLTANE, Lotfi ZEGHADNIA, Lakhdar DJEMILI, Abdalhak GHEID, Yassine DJEBBAR

Zwiększanie stężenia wolnego chloru na końcach sieci wodociągowej: Przykład miasta Souk Ahras w Algierii

STRESZCZENIE

Instytucje zaopatrzenia w wodę pitną zwracają szczególną uwagę na obecne w wodzie patogeny. Najczęściej stosowaną metodą usuwania patogenów jest chlorowanie wody w stacjach uzdatniania i w systemie dystrybucji. W Algierii użycie chloru do uzdatniania wody jest powszechnie stosowaną praktyką. Podjęto praktyczne działania, aby zwiększyć stężenie pozostalego chloru w systemie publicznego zaopatrzenia w wodę części miasta Souk Ahras (Faubourg) w Algierii znany z małego stężenia wolnego chloru (wg badań Algérienne des Eaux: ADE), szczególnie w miejscu odbioru wody. Zastosowana metoda jest kombinacją symulacji za pomocą programu EPANET2 i pomiarów terenowych. Model hydrauliczny był kalibrowany z wykorzystaniem analizy statystycznej, a obserwowane wartości były bardzo bliskie wynikom symulacji. Korzystniejsze stężenie chloru w całej sieci uzyskano po wprowadzeniu odpowiedniej jego dawki.

Słowa kluczowe: Algieria, EPANET2, miasto Souk Ahras, rozkład pozostalonego chloru, sieć wodociągowa, woda pitna