

Anna MUSZ-POMORSKA<sup>1\*</sup> and Marcin K. WIDOMSKI<sup>1</sup>

## VARIANT ANALYSIS OF THE CHLORINATION EFFICIENCY OF WATER IN A SELECTED WATER SUPPLY NETWORK

### ANALIZA WARIANTOWA EFEKTYWNOŚCI CHLOROWANIA WODY W WYBRANEJ SIECI WODOCIĄGOWEJ

**Abstract:** Chlorination of water belongs to the basic methods of its disinfection and is commonly used, permanently or periodically, as the final stage of water treatment at many water treatment stations in Poland. Although, the chlorination process is a well-known phenomenon, the selection of an appropriate dose of disinfectant is still a difficult task. The lack of chlorine in the water or its too low content (below  $0.2 \text{ mg} \cdot \text{dm}^{-3}$ ) results in the lack of microbiological protection of water flowing through the pipes. A reverse situation is also unfavourable. The use of too high doses of chlorine at the entrance to the network, on the one hand, ensures adequate disinfectant concentration even in the fittings of the network, on the other hand, it can lead to dangerous for health disinfection by-products (DBPs) including trihalomethanes (THMs). The selection of the proper dose of chlorine should take into account factors affecting its consumption, chemical parameters of water as well as hydraulic parameters of water transport. Such possibilities are available due to application of numerical modelling to study the transport of chlorine in water. The aim of the presented research is to analyse the effectiveness of chlorination of water in a selected water supply network. Simulation tests were carried out for various doses of disinfectant supplied to the network for the assumed duration of the simulation - 168 h. The qualitative model was developed in the EPANET 2.0 software using a hydraulic model of the tested network. The first order chlorine decay reaction was assumed to modelling studies, with applied literature values of decay rate of chlorine in water. The results of simulation tests of chlorine transport in the network revealed difficulties in choosing the right dose of chlorine necessary to ensure microbiological protection of water in the network. The forced flow allowed effective disinfection of water.

**Keywords:** chlorination of water, chlorine distribution in water, EPANET, modelling of chlorine transport

### Introduction

The main objective of water supply companies is to deliver water save, meeting all binding physical, chemical and microbiological requirements, water to the consumers [1, 2]. Accomplishment of these requirements is related to necessary application of various technologies of water purification, including disinfection. According to WHO [3] the process of disinfection utilizing reactive chemical compounds, including chlorine, poses the crucial role in delivery of safe water to the consumers due to developed barrier for several pathogens. The properly designed system of water disinfection by chlorine allows effective disposal of bacteria, viruses or other pathogens as well as protection of water inside the whole system of drinking water distribution, preventing its secondary pollution.

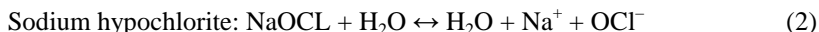
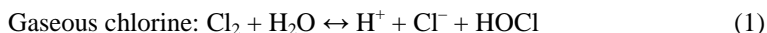
During water treatment process, chlorine is usually being supplied as compressed gas, solution of sodium hypochlorite or solid calcium hypochlorite. All used forms of chlorine are generally chemically equivalent due to quick equilibrium between dissolved chlorine

<sup>1</sup> Faculty of Environmental Engineering, Lublin University of Technology, ul. Nadbystrzycka 40B, 20-618 Lublin, Poland, phone +48 81 538 44 81

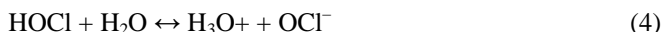
\*Corresponding author: a.musz-pomorska@pollub.pl

Contribution was presented during ECOpole'19 Conference, Polanica-Zdroj, 9-12.10.2019

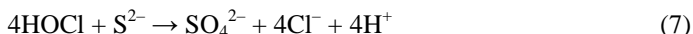
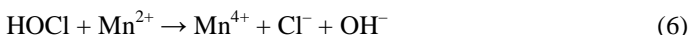
and products of dissociation of hypochlorite compounds. In relation to the form of chlorine application, the following reactions occur in water [4, 5]:



HOCl will dissociate to give hydrogen ions ( $\text{H}^+$ ) and hypochlorite ions:



Chlorine added to water decomposes in different ways, four types of reactions may be noted: (1) oxidation, (4) addition, (5) substitution, and (6) catalysed or light decomposition:



Equations (5) to (9) describe reactions of hypochlorous acid with inorganic substances, leading to the immediate use of residual chlorine. Reaction described by equation (10) occurring between HOCl and functional groups in particles of natural organic matter (NOM) available in water. All equations presented above result in the consumption of chlorine in water.

The wrongly selected dose of chlorine, both, too low and too high, unfavourably affects characteristics of water quality. Decrease in free chlorine content below the minimal level may trigger the secondary development of microorganisms [6-11]. Sustaining the minimal concentration of chlorine inside the whole water distribution system prevents water against growth of bacteria and deterioration of qualitative characteristics of water.

On the other hand, application of too high dose of chlorine disinfectant during water purification may result in occurrence of dangerous water disinfection by-products (DPBs) including trihalomethanes (THMs) as well as change of water smell and taste [3, 12-17].

Thus, the proper determination of chlorine dose required for water disinfection is crucial. According to WHO guidelines, concentration of free chlorine in points of water delivery should be in range 0.2-0.5  $\text{mg} \cdot \text{dm}^{-3}$  [3]. Polish standards [2] determine the acceptable concentration of chlorine in drinking water as 0.3  $\text{mg} \cdot \text{dm}^{-3}$ .

Chlorine, added to water during its disinfection process decomposes, as it was mentioned before, as a result of chemical reaction with inorganic and organic compounds available in transported water. Chlorine, as a strong oxidant is being used during interaction with sediments, product of corrosion as well as biomass, deposited on the inner walls of pipes. Thus, its constant decomposition in time is being observed, irrespectively to availability of other factors affecting its usage [18-20]. The total sum of all decomposition processes occurring in water body and in the boundary layer is known as the chlorine demand by water.

Taking into account the large number of factors influencing chlorine decomposition and complexity of processes occurring inside the water supply system, it is hard to correctly predict the final chlorine content in water, especially in large piping systems, operating under unfavourable technical and hydraulic conditions. Thus, the new tools supporting this process are still researched. Nowadays, the numerical models, allowing to reflect the variable hydraulic conditions inside water supply network as well as the individual factors affecting decomposition of chlorine, are commonly used in the studies of chlorine transport.

The key factor related to application of different equations of chlorine decomposition is determination of its decay constants, which, in turn, are related to quality of source water, its temperature, Reynolds number and properties of pipes materials. Therefore, the total constant of chlorine decay ( $k$ ) is expressed and sum of two factors: decay in water constant ( $k_b$ ) and decay in boundary layer ( $k_w$ ) [21].

The simplest and popular model of chlorine decay assumes that chlorine concentration is proportional to its initial content, according to equation:

$$c = c_0 e^{-kt} \quad (11)$$

where:  $c$  - chlorine concentration in time  $t$  [ $\text{mg} \cdot \text{dm}^{-3}$ ],  $c_0$  - initial chlorine concentration [ $\text{mg} \cdot \text{dm}^{-3}$ ],  $k$  - constant of chlorine decay rate [ $\text{min}^{-1}$ ],  $t$  - time [min].

Recent development of numerical techniques and software for water distribution networks modelling allows increased application of modelling studies in water supply companies. Available pieces of computer software, e.g. EPANET 2.0 [22], Aquis [23] or Mike Urban [24] based on reported kinetic model of chlorine decay allows high-accuracy prediction of applied disinfectant at nodes of tested networks [6, 25-27].

The EPANET modelling software, due to its free access, gained huge popularity. The kinetics of chlorine decomposition in this software was described by the first order model [22]. The research reported by Ozdemir and Ucak [28] covering comparison of numerical modelling results obtained in EPANET and DYNAQU computational algorithm to results of chlorine concentration measured at nodes of water supply system showed the satisfactory agreement between modelled and measured values.

The aim of this paper was variant analysis of water chlorination efficiency for selected municipal water supply network. The performed analyses of chlorine transport and decay was supplemented by studies over water age. The qualitative numerical calculations were performed in EPANET model, basing on the calibrated hydraulic model of the network.

## Materials and methods

### *Object of study*

Our studies were performed for municipal water supply network delivering drinking water to approx. 8600 residents. The studied network has mixed structure and is supplied with water by three water supply stations, but station WSS III works as support and is unable to provide required water demand during emergency situation. The length of whole network is 57.3 km and consists of asbestos-cement, polyvinyl chloride (PVC) and polyethylene (PE) pipes. Diameters of pipelines in the network vary in range 500-90 mm, while connection pipes 63-25 mm. The pressure head at the beginning of the network is being sustained at the constant level of approx. 0.4 MPa.

### Hydraulic model

The hydraulic model of studied network was developed in EPANET 2.0 computational software. This model consists of 444 lines, 410 nodes and three reservoirs combined with pumping stations (described in Figure 1 as WSS-I, WSS-II and WSS-III). Calculations of pressure loss were performed according to Darcy-Weisbach formula. Diameters, lengths and elevations of pipelines introduced to our model were obtained from the situation map.



Fig. 1. Network scheme with marked characteristic nodes and pipelines

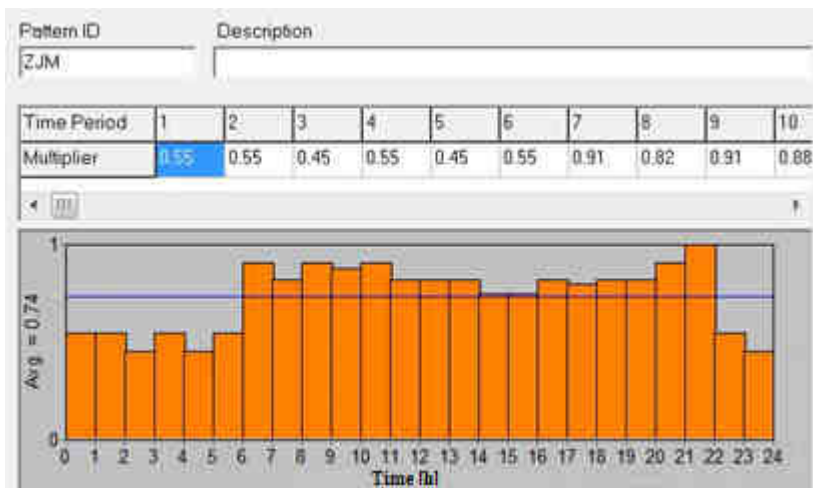


Fig. 2. Water demand pattern

The computable water demands were based on the real readings from domestic watermeters ( $0.003\text{--}0.97 \text{ dm}^3 \cdot \text{s}^{-1}$ ) while the applied water demand patterns were based on network watermeters readings from water supply stations (Fig. 2).

The maximal water flow rate inside the studied network occurs at 21.00 and reaches the level  $32.6 \text{ dm}^3 \cdot \text{s}^{-1}$ , while the lowest water demand equalled  $14.33 \text{ dm}^3 \cdot \text{s}^{-1}$  and appears at 02.00. The Manning's roughness coefficient values for materials of studied pipelines were accepted after literature reports as  $k = 1.5 \text{ mm}$  for cast iron pipes,  $k = 0.6 \text{ mm}$  for asbestos-cement pipelines and  $k = 0.025 \text{ mm}$  for plastic pipelines.

### Qualitative model

The variant analyses of water chlorination efficiency inside the tested water supply network were performed in EPANET 2.0 software, developed and published by EPA (Environmental Protection Agency), USA, with usage of the hydraulic model of the network. The applied hydraulic model was previously calibrated in relation to pressure and water flow distributions.

Due to lacking in situ measurements, values of chlorine decay constants were assumed after literature. Value of chlorine decay constant in water was assumed as  $k_b = 0.012 \text{ h}^{-1}$ , after Hua et al. [29]. The assumed value is similar to the  $k_b = 0.0182 \text{ h}^{-1}$  determined empirically and reported by Musz-Pomorska et al. [30] for the similar network. The value of chlorine decay constant in the boundary layer,  $k_w = 0.16 \text{ h}^{-1}$ , was assumed as average of values proposed by Hallama et al. [31] for different pipeline materials.

Water inside the studied network is chlorinated periodically, in cases of water pollution danger or after repair works. According to information obtained from the local water supply company, water delivered to the networks belongs to the semi-hard (of medium hardness) with alkaline pH. Iron content in water reaches level of  $60 \mu\text{g} \cdot \text{dm}^{-3}$ , while compounds of chlorites, ammonium and nitrites are available in trace quantities.

In order to determine the water chlorination efficiency inside the studied water distribution network, three variants of modelling calculations of chlorine transport and decomposition were performed, with different assumed dose of disinfectant during operation of all water supply stations. All accepted variants of calculations are presented in Table 1.

Variants of chlorine simulation

Table 1

Variant	Working of Water Supply Station	Initial concentration of chlorine $c_0$ [ $\text{mg} \cdot \text{dm}^{-3}$ ]	Chlorine dose [ $\text{mg} \cdot \text{dm}^{-3}$ ]
I	WSS-I, WSS-II, WSS-III	0	0.3
II		0	0.5
III		0	1.0

The applied modelled dose of chlorine was accepted after available literature, including WHO guidelines [3], according to which concentration of free chlorine in water delivered to the customers should be in range  $0.2\text{--}0.5 \text{ mg} \cdot \text{dm}^{-3}$ . Thus, to meet such value of free chlorine inside the distant pipelines, the initial dose at WSSs should be respectively greater.

Additionally, simulations of water age inside the pipelines were also performed. The assumed time of simulation was equal 168 h. The accepted time duration of simulation is with agreement with “long” time of water detention inside the pipes, according to literature equal 3 days [32].

## Results

In order to present chlorine decomposition and water age inside pipelines of the studied municipal water distribution system, 10 nodes and 10 pipelines, assumed as representative, were selected. The choice was influenced by distance to water pumping station, daily change of hydraulic characteristics and range of the network. The selected localizations of reference nodes and lines are presented in Figure 1. Table 2 presents time-related changes of modelled free chlorine concentration in selected nodes of the tested network.

Table 2

Chlorine concentration on selected nodes of the network

Variant	Time [h] Number of node	Chlorine concentration [ $\text{mg} \cdot \text{dm}^{-3}$ ]									
		1	2	3	4	5	6	7	8	9	10
I	12	0.25	0.00	0.22	0.18	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.25	0.08	0.20	0.19	0.00	0.00	0.00	0.03	0.07	0.00
	48	0.25	0.09	0.20	0.19	0.00	0.11	0.05	0.03	0.07	0.00
	72	0.25	0.09	0.20	0.19	0.06	0.11	0.05	0.03	0.07	0.07
	168	0.25	0.09	0.20	0.19	0.06	0.11	0.05	0.03	0.07	0.07
II	12	0.42	0.00	0.37	0.31	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.41	0.11	0.34	0.30	0.00	0.00	0.00	0.05	0.11	0.00
	48	0.41	0.11	0.34	0.30	0.00	0.19	0.07	0.05	0.11	0.11
	72	0.41	0.11	0.34	0.30	0.11	0.19	0.07	0.05	0.11	0.14
	168	0.41	0.11	0.34	0.30	0.11	0.19	0.07	0.05	0.11	0.14
III	12	0.83	0.00	0.74	0.61	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.82	0.23	0.68	0.61	0.00	0.00	0.00	0.11	0.23	0.00
	48	0.82	0.24	0.68	0.60	0.00	0.39	0.15	0.12	0.23	0.00
	72	0.82	0.24	0.68	0.60	0.22	0.38	0.16	0.11	0.23	0.23
	168	0.82	0.24	0.68	0.60	0.21	0.38	0.16	0.11	0.23	0.23

Grey colour indicates values equal or higher  $0.2 \text{ mg} \cdot \text{dm}^{-3}$ , required by WHO [3] as the minimal concentration of chlorine in drinking water

The results of selected hydraulic characteristics of water flow inside the tested pipelines during the hour of maximum water demand are presented in Table 3.

The obtained results of modelled chlorine transport inside the pipelines of studied network, with assumed variable initial doses of disinfectant, shows that in none of tested computational variants the required satisfactory level of water protection was achieved, due not reaching the minimal concentration of free chlorine required by WHO (min.  $0.2 \text{ mg} \cdot \text{dm}^{-3}$ ).

In case of the modelled lowest doses of chlorine applied during drinking water treatment (Variants I) the minimal chlorine concentration was noted only in the nodes very close to water supply station (nodes 1 and 3), characterized by the highest velocity and volumetric flow rate of water (Table 3).

Parameters of flow in selected pipes at 168 hours of modelling

Table 3

Description	Pipe	Diameter of pipe [mm]	Flow [ $\text{dm}^3 \cdot \text{s}^{-1}$ ]	Velocity [ $\text{m} \cdot \text{s}^{-1}$ ]
			Variant I-III	
1	41	250	4.12	0.08
2	86	100	1.04	0.13
3	228	150	2.65	0.15
4	M17	250	3.99	0.08
5	424	100	0.06	0.01
6	159	100	0.07	0.01
7	402	150	0.26	0.01
8	250	65	0.70	0.21
9	427	150	1.95	0.11
10	20	100	0.05	0.01

The obtained results of calculations showed similar situation for chlorine dose equal  $0.5 \text{ mg} \cdot \text{dm}^{-3}$ . The concentration of free chlorine higher than threshold value of  $0.2 \text{ mg} \cdot \text{dm}^{-3}$  was observed only in three selected representative nodes. The slight increase in free chlorine, in relation to Variant I, was observed in the remaining points, however, below the required minimal value. In case of disinfectant dose equal  $1.0 \text{ mg} \cdot \text{dm}^{-3}$  (Variant III) the best results of chlorination were observed. The minimal threshold value of free chlorine concentration was exceeded in 8 of 10 representative nodes for Variant III, with all water supply stations operational.

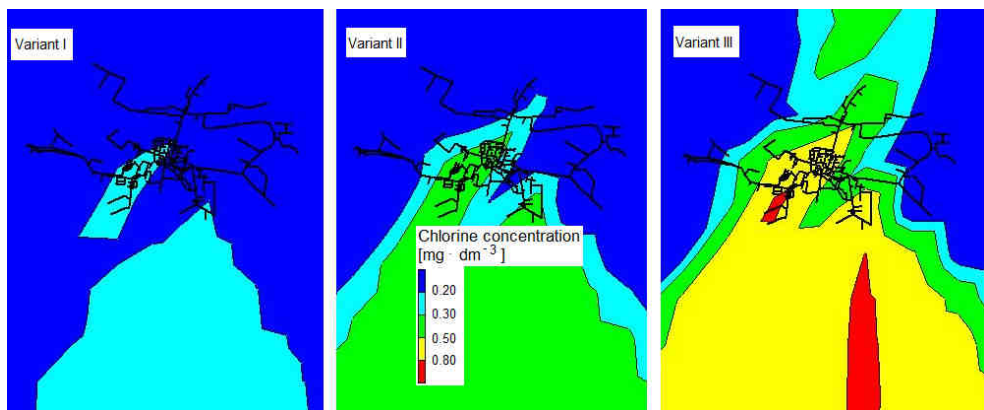


Fig. 3. Scheme of counter lines dividing the chlorine concentration in pipelines

Taking into account WHO's guidelines and maximum allowed concentration of free chlorine in water equal  $0.5 \text{ mg} \cdot \text{dm}^{-3}$  the exceeding of this threshold value was observed only for the  $1.0 \text{ mg} \cdot \text{dm}^{-3}$  initial dose of disinfectant. The nodes with determined increased free chlorine concentration are located on the main pipeline (diameters 250 and 150 mm) (Table 3), without the direct connections to households.

Figure 3 shows scheme of isolines differentiating free chlorine concentration for selected variants of water supply. The presented scheme of isolines for chlorine concentration in water (Fig. 3) shows that in all tested variants the highest concentrations of free chlorine are visible in pipelines close to water supply station, while the lowest chlorine content was noted for the perimeter pipelines. These observed low concentrations of free chlorine in the distant parts of the network is related to low water demands, resulting in very low velocities of water flow (Table 3).

Table 4

Water age on selected nodes of the network

Variant	Water age [h]									
	1	2	3	4	5	6	7	8	9	10
I-III	4.1	15.7	6.1	9.8	55.8	38.6	40.4	21.3	17.4	57.8

Additionally, the prolonged time of water retention (long water age) was observed in distant pipelines of the network (Table 4), which also affects values of free chlorine concentration in water. The nodes in which the lowest values of free chlorine concentration in water were observed, were also characterized by the longest water age, exceeding even 4 days. Such prolonged time of water retention in pipelines results in spontaneous chlorine decay as well as the extended duration of chlorine contact with organic and inorganic compounds available in water and on inner walls of pipes.

## Conclusion

Selection of the proper disinfectant dose during the process of water disinfection, allowing to obtain the minimal required concentration of residual chlorine in water, without exceeding the maximum allowed contents, in all nodes of the water distribution network is a very difficult task, especially in systems operating under unfavourable conditions or suffering technical problems. Low water demands, flow velocities far below the required minimal values and extended water age trigger deteriorated water exchange in the system, thus, constrict chlorine transport to the distant, perimeter parts of the network.

Analysis of the obtained results of chlorine transport modelling in the municipal water supply network, with assumed various initial doses of disinfectant, showed that, regardless the initial dose, there are visible pipelines in the studied system in which concentration of chlorine is below the required minimal value ( $0.2 \text{ mg} \cdot \text{dm}^{-3}$ ).

These pipelines are located at the perimeter of the network and are characterized by very low values of water flow velocity (below  $0.01 \text{ m} \cdot \text{s}^{-1}$ ) and long water age (above three days). Increased initial disinfectant dose caused increase in its concentration in close vicinity of water supply stations, even above the maximum allowable values described by Polish ( $0.3 \text{ mg} \cdot \text{dm}^{-3}$ ) and WHO ( $0.5 \text{ mg} \cdot \text{dm}^{-3}$ ) standards.



Assertion of the required concentration of free chlorine in the whole, vast water supply system with disinfection performed in one or several close locations may be very hard to achieve.

Taking into account assumption of literature values of chlorine decay to modelling and missing calibration of qualitative model the obtained results should be treated as preliminary but providing interesting and useful information concerning chlorine distribution inside the water supply network.

### Acknowledgements

The hydraulic model used in the article was developed as part of the master's thesis of Rafał Koconowski. The title of thesis is „Modelling of hydraulic conditions of water supply network”.

### References

- [1] Commission Directive (EU) 2015/1787 of 6 October 2015 amending Annexes II and III to Council Directive 98/83/EC on the quality of water intended for human consumption. <http://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A32015L1787>.
- [2] Regulation of the Minister of Health of 2015 on the quality of water intended for human consumption. DzU 2015, poz. 1989. <http://isap.sejm.gov.pl/DetailsServlet?id=WDU20150001989>.
- [3] WHO Guidelines for drinking water quality, 4th ed. Geneva: WHO; 2011. [http://www.who.int/water\\_sanitation\\_health/publications/2011/dwq\\_guidelines/en/](http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/).
- [4] Haas CN. Disinfection. In: Letterman RD, editor. Water Quality and Treatment, vol. 5. Denver, Colorado: AWWA; 1999.
- [5] Gang DC, Clevenger TE, Banerji SK. J Environ Inform. 2003;1(1):21-7. DOI: 10.3808/jei.200300003.
- [6] Blokker M, Vreeburg J, Speight V. Procedia Eng. 2014;70:172-80. DOI: 10.1016/j.proeng.2014.02.020.
- [7] Zhao Y, Yang YJ, Shao Y, Neal J, Zhang T. Water Res. 2018;141:32-45. DOI: 10.1016/j.watres.2018.04.048.
- [8] Goyal RV, Patel HM. Appl Water Sci. 2015;5:311-9. DOI: 10.1007/s13201-014-0193-7.
- [9] Boccelli DL, Tryby ME, Uber JG, Summers RS. Water Res. 2003;37:2654-66. DOI: 10.1016/S0043-1354(03)00067-8.
- [10] Chang EE, Chiang PC, Chao SH, Lin YL. Chemosphere. 2006;64(7):1196-203. DOI: 10.1016/j.chemosphere.2005.11.036.
- [11] Rand JL, Gagnon GA, Knowles A. Water Sci Technol. 2014;9(4):491-501. DOI: 10.2133/wpt.2014.055.
- [12] Digiano FA, Zhang W. JAWWA. 2005;97(1):77-85. DOI: 10.1002/j.1551-8833.2005.tb10805.x.
- [13] Ates N, Kaplan SS, Sahinkaya E, Kitis M, Dilek FB, Yetis U. J Hazard Mater. 2007;142(1-2):526-34. DOI: 10.1016/j.jhazmat.2006.08.076.
- [14] Villanueva CM, Gagniere B, Monfort C, Nieuwenhuijsen MJ, Cordier S. Environ Res. 2007;103:211-20. DOI:10.1016/j.envres.2006.11.001.
- [15] Tinker SC, Moe CL, Klein M, Flanders WD, Uber J, Amirtharajah A, et al. J Water Health. 2009;7(2):332-43. DOI: 10.2166/wh.2009.022.
- [16] Brown D, Bridgeman J, West JR. Rev Environ Sci Biotechnol. 2011;10:79-99. DOI: 10.1007/s11157-011-9229-8.
- [17] Jae CA, Su Won L, Kevin Y, Ja Yong K. Application of EPANET for the determination of chlorine dose and prediction of THMs in a water distribution system. Sustain Environ Res. 2012;22(1):31-8. [https://businessdocbox.com/77194481-Green\\_Solutions/Application-of-epanet-for-the-determination-of-chlorine-dose-and-prediction-of-thms-in-a-water-distribution-system.html](https://businessdocbox.com/77194481-Green_Solutions/Application-of-epanet-for-the-determination-of-chlorine-dose-and-prediction-of-thms-in-a-water-distribution-system.html).
- [18] Kim H, Kim S, Koo J. Procedia Eng. 2015;119:370-8. DOI: 10.1016/j.proeng.2015.08.897.
- [19] Clark RM, Haught RC. J Water Res Planning Manage. 2005;131(3):208-17. DOI: 10.1061/(ASCE)0733-9496(2005)131:3(208).
- [20] Powell JC, Hallam NB, West JR, Forster CF, Simms J. Water Res. 2000;34(1):117-26. DOI: 10.1016/S0043-1354(99)00097-4.

- [21] Monteiro L, Viegas RMC, Covas DIC, Menaia J. Modelling chlorine residual decay as influenced by temperature. *Water Environ J*. 2015;29:331-7. DOI: 10.1111/wej.12122.
- [22] Rossman LA. EPANET 2 Users Manual. Risk Reduction Engineering Laboratory. Cincinnati, OH: US Environmental Protection Agency; 2000. <ftp://84-255-254-95.static.t-2.net/Epanet%202.0/EN2manual.pdf>.
- [23] AQUIS, Water supply network management. <http://www.it.kelvin.pl>.
- [24] Mike Urban, Modeling of water supply systems. <http://www.mikebydhi.com>.
- [25] Tiruneh AT, Debessai TY, Bwembya GC, Nkambule SJ, Zwane L. *JWARP*. 2019;11(1):37-52. DOI: 10.4236/jwarp.2019.111003.
- [26] Roopali V, Goyal H, Patel M. *Appl Water Sci*. 2015;5:311-9. DOI: 10.1007/s13201-014-0193-7.
- [27] Monteiro L, Figueiredo D, Dias S, Freitas R, Covas D, Menaia J, et al. *Procidia Eng*. 2014;70:1192-200. DOI: 10.1016/j.proeng.2014.02.132.
- [28] Ozdemir ON, Ucak A. Simulation of chlorine decay in drinking-water distribution systems. *J Environ Eng*. 2002;128(1):31-9. <https://ascelibrary.org/doi/abs/10.1061/%28ASCE%290733-9372%282002%29128%3A1%2831%29?src=recsys&>.
- [29] Hua F, West JR, Barker RA, Forster CF. Modelling of chlorine decay in municipal water supplies. *Water Res*. 1999;33(12):2735-46. <https://www.sciencedirect.com/science/article/abs/pii/S0043135498005193>.
- [30] Musz-Pomorska A, Widomski MK, Matczuk A, Sadura K. *E3S Web Conf*. 2019;100:00054. DOI: 10.1051/e3sconf/201910000054.
- [31] Hallam NB, West JR, Forster CF, Powell JC, Spencer I. *Water Res*. 2002;36:3479-88. DOI: 10.1016/S0043-1354(02)00056-8.
- [32] Shu S, Liu S, Wang X, Yu L, Shu S, Zhang D, et al. *Int Conf MACE*. 2010;1918-21. DOI: 10.1109/MACE.2010.5536510.

## ANALIZA WARIANTOWA EFEKTYWNOŚCI CHLOROWANIA WODY W WYBRANEJ SIECI WODOCIĄGOWEJ

Wydział Inżynierii Środowiska, Politechnika Lubelska, Lublin

**Abstrakt:** Chlorowanie wody należy do podstawowych metod jej dezynfekcji i jest powszechnie stosowane stale lub okresowo jako końcowy etap uzdatniania wody na wielu stacjach uzdatniania wody w Polsce. Mimo iż sam proces chlorowania jest zjawiskiem dobrze znanym, to dobór odpowiedniej dawki dezynfektanta jest nadal zadaniem sprawiającym trudności. Brak chloru w wodzie bądź jego zbyt mała zawartość (poniżej  $0,2 \text{ mg} \cdot \text{dm}^{-3}$ ) skutkuje brakiem ochrony mikrobiologicznej wody przepływającej w przewodach. Niekorzystna jest również sytuacja odwrotna. Stosowanie zbyt dużych dawek chloru na wejściu do sieci z jednej strony zapewnia odpowiednie stężenie dezynfektanta nawet w końcowych odcinkach sieci, z drugiej strony może prowadzić do powstawania niebezpiecznych dla zdrowia ubocznych produktów dezynfekcji, w tym trihalometanów. Dobór odpowiedniej dawki chloru powinien uwzględniać czynniki wpływające na jego zużycie, parametry chemiczne wody, a także parametry hydrauliczne transportu wody. Takie możliwości daje zastosowanie modelowania numerycznego do badania transportu chloru w wodzie. Celem prezentowanych badań jest analiza efektywności chlorowania wody w wybranej sieci wodociągowej. Badania symulacyjne przeprowadzono dla różnych dawek dezynfektanta podawanych do sieci przez założony czas trwania symulacji - 168 godzin. Model jakościowy wykonano w programie EPANET 2,0 przy zastosowaniu modelu hydraulicznego badanej sieci. Do obliczeń symulacyjnych rozkładu chloru przyjęto pierwszorzędową reakcję jego rozkładu oraz literaturowe wartości stałych szybkości jego rozkładu. Wyniki badań symulacyjnych transportu chloru w sieci uwiarygodniły trudności w doborze odpowiedniej dawki chloru niezbędnej do zapewnienia ochrony mikrobiologicznej wody w badanej sieci. Dopiero wymuszenie przepływu pozwoliło na efektywną dezynfekcję wody.

**Słowa kluczowe:** chlorowanie wody, rozprzestrzenianie chloru w wodzie, EPANET, modelowanie transportu chloru