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Self-Degradation of Water Quality in Distribution Networks

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Abstract: **In the paper is investigated the influence of water flow rates through pipelines on drinking water quality in populated areas. Water residence time in networks, for more than seven days in case of buried pipes and two days for above-ground pipes, promotes the development of biochemical systems in case of low (0.5 m/s) and very low flow velocities with detrimental consequences on drinking water quality. In this case the residual chlorine decreases below the allowed technical norm limits in the distribution pipes. The case study was conducted on the distribution network of Timişoara using the EPANET program in which the hydraulic parameters (flow, diameter, velocity, loss of head) are correlated with the water stagnation periods (residents) on pipe sections with residual chlorine allowed at every point of consumption.**

1. INTRODUCTION

The water distribution system from populated centers, containing pipes, fittings, measuring devices and auxiliary constructions will provide water from the main constructions to the customers or it will increase the pressure in the network. It is important the distribution system to assure the quantity and quality of water, and also the working pressure for each customer at the lowest cost [6]. The needed quantity of water in populated centers is established depending on the number of customers, locality site and infrastructure level with respect to the cold and warm water.

Because of the social-economical changes which took place in Romania after 1989, there has been a substantial reduction of water specific consumption with after-effects on the existing networks in terms of flow hydraulic parameters modification and further on with a consequence on the biological stabilization of the distributed water. Qualitative degradation of water from distribution networks is determined by the followings: appearance and development of biological ecosystems; accidental pollution; formation of some deposits at low velocities of water flow; increase of transit time and modification of hydraulic parameters of water flow
[1], [2], [13].

The biologic ecosystems which might be formed in the water distribution network have the organic carbon as main source of energy, provided by the dissolved substances from treated water. The bacteria developed in water and like a thin coating on pipe walls, even if not dangerous for people could provide modifications on water quality in taste or microbiologically. In order to avoid bacteria proliferation there can be applied disinfections with gaseous chlorine, sodium hydrochloric, ozone or pipe cleaning [2].

The low velocities of water flow through the pipe network favor the laying down of sediments and contributes to the decrease of residual chlorine under admission limits by sanitary norms (0.1…0.5 mg/dm3) with a negative influence upon the water quality. These problems can be avoided by changing the evolution of chlorine in water distribution networks. [10], [15]

2. THEORETICAL BASIS CONCERNING THE EVOLUTION OF CHLORINE CONCENTRATION IN DRINKING WATER DISTRIBUTION NETWORKS

Chlorine is a disinfectant with remanent action which reacts when it is introduced in the water distribution system with the mineral and organic compounds, with microorganism bacteria existing in water and on the pipe walls. Chain reactions of chlorine consumption depend on water temperature, compounds that react with chlorine, concentration of chlorine that is introduced in water and concentration of reaction compound.

The chain reaction can be written as follows (Eq. 1):

$$\frac{dC}{dt} = -k \cdot C \qquad (1)$$

or

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$$\frac{dC}{C} = -Kdt \qquad (2)$$

After integration, there is obtained:

$$C = C_O \bullet \exp(-kt) \qquad (3)$$

Where:
C – Concentration of free chlorine at the time t;
in water;
k – Kinetically constant for chlorine consumption;
t – Time of reaction;
C_o–Initial concentration of chlorine that was introduced; Fig. 3. Chl
Fig. 3.

Variation of chlorine consumption takes place in two stages: first stage refers to rapid chlorine consumption and the second stage refers to gross chlorine consumption which takes place after a one-order kinetics described by Equation 3 as transmitted in integral form [5]:

$$\ln\frac{C}{C_o} = -k \cdot t \qquad (4)$$

Graphical representation of equations 3 and 4 is found in Figure 1:

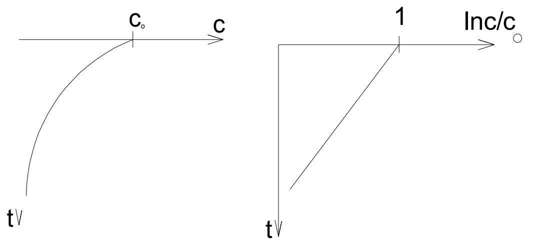

Fig.1. Variation of the residual chlorine depending on the time

Equation (3) was accepted for simulation of free chlorine concentration from the distribution networks, depending on durations of water flows through pipes [2], [4], [11]. To modify chlorine concentration (C) in water distribution networks, the following hypothesis can be considered: the regime of water movement is permanent; the flow is a piston type, without axial dispersion; the mixture on junctions is complete; the dispersion of chlorine through the network follows the mass conservation law; the chlorine concentration in the downstream junction depends on the concentration from the upstream junction (Fig. 2), Eq. (3); the chlorine concentration from every junction is obtained by the average of chlorine concentration from the pipes which undergo through junction "j" (Fig. 3) using Eq. (5).

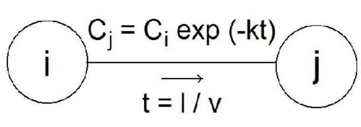

Fig. 2. Chlorine consumption between two consecutive junctions

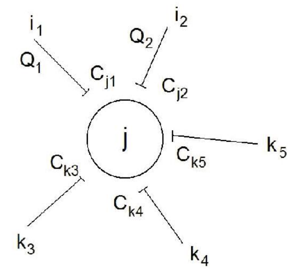

Fig. 3. Chlorine concentration in junctions depending on the number of portions which undergo through junction

Considering that $C_{k3} = C_{k4} = C_{k5} = C_j$, then the concentration of chlorine in the junction (j) is calculated like weighted average with Eq. (3):

$$C_j = \frac{\sum_{1}^{j,i} C_j \cdot Q_i}{\sum_{1}^{i} Q_i} \qquad (5)$$

On each portion (i-j) there are two unknowns (C_i. C_j) which represent the chlorine concentrations on portions (p). If the initial chlorine concentrations on the portions (p) are known, the number of unknowns is equal with the number of the available relation (p + n) (n – number of junction) and could be in this way defined by the hydraulic running regime of the network and also by the kinetic constant (k) for the network or for each portion. According to Wable the kinetic constant (k) can be established on each portion of the distribution network, as it follows in Fig. 4 [12].

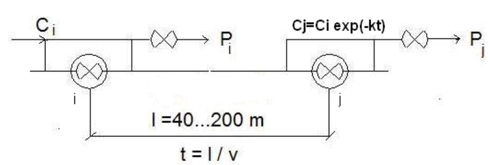

Fig. 4. Calculus scheme of the kinetic constant k

Through the by-pass from the point (i) the dose of chlorine C_i is introduced and the sample P_i is taken. Further on, the kinetic reaction of the chlorine dose C_i with the water which passes through portion i-j is studied. Through the by-pass from the point (j) the sample P_j is taken and the kinetic reaction of dose chlorine C_i with the water which passes the portion i-j is studied.

The difference of chlorine consumption (ΔC) between the samples P_i and P_j, for the same interval of time, represents the free chlorine reduced by the wall of pipe i-j. In another method the determination of the kinetic constant k could be done by measuring the free chlorine in several points of the network (Fig. 4). The calculus algorithm for the simulation of chlorine evolution through the distribution networks consists of establishing water velocities of stationary time on the network portions and of concentrations of free residual chlorine in junctions and terminals of branches. The velocities in the pipe networks are established according to the condition that the water stationary time in underground pipes can not be more than seven days and two days in surface pipes [7], [9].

In Table 1 the minimal admissible velocities that resulted from the condition of the minimum stationary time of water from underground pipes and reservoirs (7 days) and for surface pipes and reservoirs (2 days) are presented depending on the stationary time and the length of the pipes [8].

Table 1. Velocity in pipes depending on stationary time

No.	Pipe types	L (m)	V (mm/s)	
			Ground pipes	Surface pipes
1	Pipes between/on branches	12	0.0198	0.0690
		15	0.0248	0.0868
		25	0.0413	0.1446
		50	0.0826	0.2894
2	Branches	100	0.1625	0.5487
		150	0.2480	0.8680
		200	0.3307	1.1574
		250	0.4133	1.4467
3	Main and secondary pipes	300	0.4960	1.7361
		400	0.6614	2.3148
		500	0.8267	2.8935
		600	0.9920	3.4722

In the buried pipelines the stationary time cannot exceed more than 7 days. In above ground pipeline the stationary time cannot exceed more than 2 days.

3. HYDRAULIC SIMULATION OF THE WATER SUPPLY SYSTEM OF TIMISOARA CITY

Hydraulic simulation of the water supply system of Timişoara city (350.000 inhabitants) was done with the EPANET program (EPANET, 2006). Using this program makes it possible to establish the discharges, the velocities on each pipe, the pressure in each network junction, the reservoir water levels, the stationary time of water in networks, the residual chlorine in different parts of the distribution system. The distribution network (Fig. 5) is composed by 11.294 portions, the diameters are between 50 mm and 1.600 mm, the total length of the distribution system is 606.423 m from which are 15.764 m branches, 10.113 junctions and a number of 2.400 branches. The distribution system of Timişoara city has three sources of water (water treatment plant number 1,

water treatment plant number 2-4 and water treatment plant number 5. Each of them has a running regime which depends on the water consumption.

Water treatment plant number 1 is a source which takes water from underground and which works in three different pumping regimes:

- **P2, which has $Q = 976 - 1044\ m^3/h$ and $H_p = 19$ m CA, between 0 - 6 hours;**
- **P4, which has $Q = 997 - 1087\ m^3/h$ and $H_p = 25$ m CA, between 6 - 10 and 22 - 24 hours;**
- **P1, which has $Q = 2340 - 2592\ m^3/h$ and $H_p = 28$ m CA, between 10 - 22 hours.**

At the water treatment plant number 2 (water surface source) the water distribution is done by a pump which assures two pressure regimes: night regime $Q = 2250 \div 2646\ m^3/h$, $H_p = 19$ mCA, between 0 - 6 and 22 - 24 hours; day regime $Q = 2948 - 4734\ m^3/h$, $H_p = 28$ mCA, between 6 - 22 hours.

The water treatment plant number 5 works with a pump: $Q = 660\ m^3/h$ and H_p=23 m CA, between 20-22 hours.

4. RESULTS AND DISCUSSION

To have a first-class appreciation of the functionality of the system two different possibilities of simulation were considered:

The First Possibility: Concentrations of the water losses in junctions that are nearby the water treatment plants are proportional to the pumped discharges. This will allow the evaluation of the system without water losses. In this case it could be possible to observe the advantageous and disadvantageous functionality conditions for reduced velocities and maximum stationary time which will lead to the decrease of water quality. **The Second Possibility:** The distribution of the water losses will be considered proportional to the discharges used by each consumer. In this case the discharge which is pumped into the network has to be totally used.

Comparing the two considered simulation possibilities, the afferent losses could be established for each junction, pipe or area. These losses need to be correlated with the real discharges obtained by direct measurements. In order to simulate the water quality, doses of residual chlorine were introduced in each reservoir identical with the doses introduced in each water treatment plant.

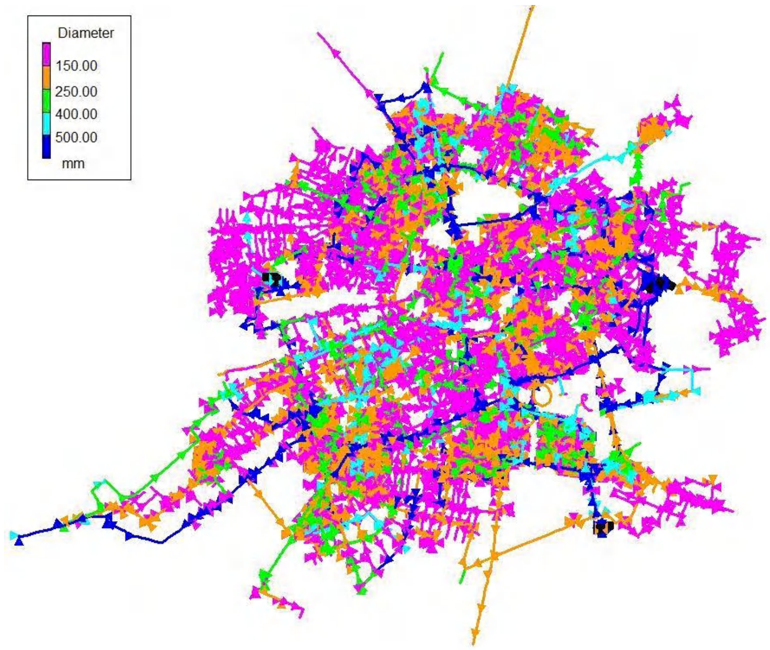

Fig. 5. The pipes diameters of the distribution system

With the help of EPANET program it was possible to simulate the consumption of chlorine in the network. Using this program there were tested two alternatives. In the first alternative, the dose of chlorine was introduced at the water treatment plant number 1 and number 5, situation which allows the graphical visualization of ground water influence upon the water from the network. In the second alternative, the dose of the chlorine was introduced just at the water treatment plant number 2-4, situation which allows the graphical visualization of the influence of surface water upon the water from the network. In the distribution system the physical, chemical and biological reactions appear at the interface of water with the pipe material, the residual chlorine has to be maintained in pipes between the admissible limits 0.1 - 0.5 mg/dm^3 [9],[12].

In Fig. 6 and 7 is highlighted the distribution of residual chlorine concentrations below 0.4 mg/l in case of chlorine injection at the plants number 1 and 2-4 after 52 and 68 hours of simultaneous operation [15].

The north part of the city is supplied from surface water sources (water treatment plant number 2-4) and the south part of the city is supplied from ground water sources (water treatment number 1). From the simulations performed with the EPANET and also from field measurements it can be noticed that the chlorine concentration in the network is between 0.3 – 0.5 mg/l. In the point of the network where is made the mixture of water provided from underground and water provided from surface, the chlorine concentration decreases at 0.01 to 0.3 mg/l, while in the peripheries of the city the concentration is between 0.00 and 0.05 mg/l. If 0.6 mg/l of chlorine are introduced at the water treatment plant number 2-4 and 0.5 mg/l at the water treatment plants number 1 and 5, there can be observed five areas in which the concentration of the residual chlorine differs after 52 and 68 hours (Table 2), [14], [15].

If these concentrations are maintained more than 168 hours (seven days) it will appear the auto-pollution risk of the water distributed to consumers.

Table 2. Residual chlorine concentration on some areas of the city depending on stationary time

Area	Residual chlorine concentration (mg/dm^3)	Stationary time (hours)	Coated areas (percentages)	Localization
1	> 0.4	< 24	10 %	South – North
2	0.2 - 0.4	24 - 48	60 %	South – West
3	0.1 - 0.2	48 - 72	20 %	West
4	0.01 - 0.1	72 - 96	10 %	West
5	< 0.01	> 96	0.01 %	Plopi Quarter

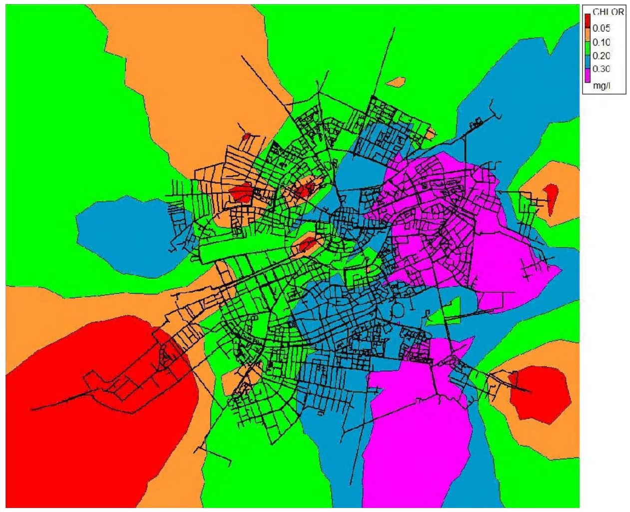

Fig. 6. Residual chlorine distribution after 52 hours

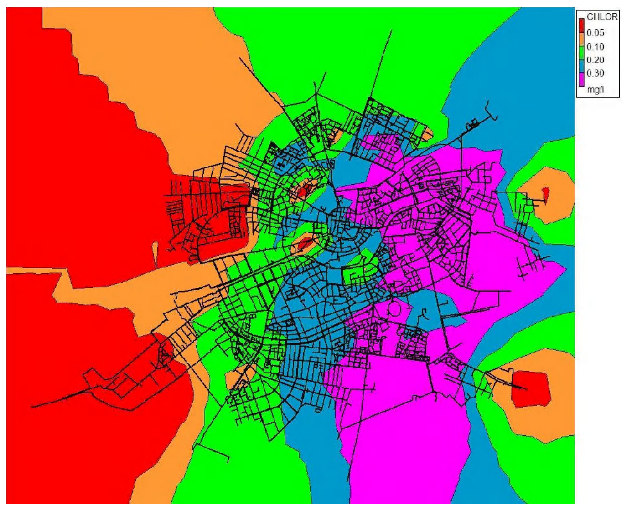

Fig.7. Residual chlorine distributions after 68 hours

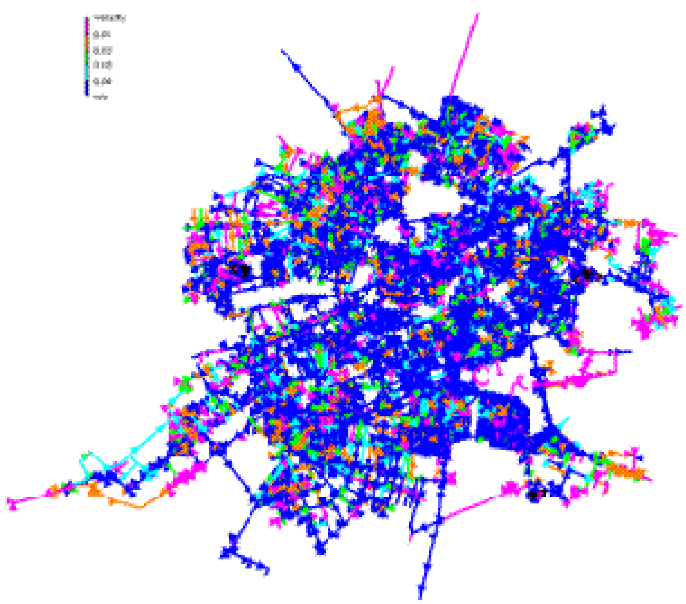

Fig. 8 Distribution of the water velocities in the distribution system after 68 hours

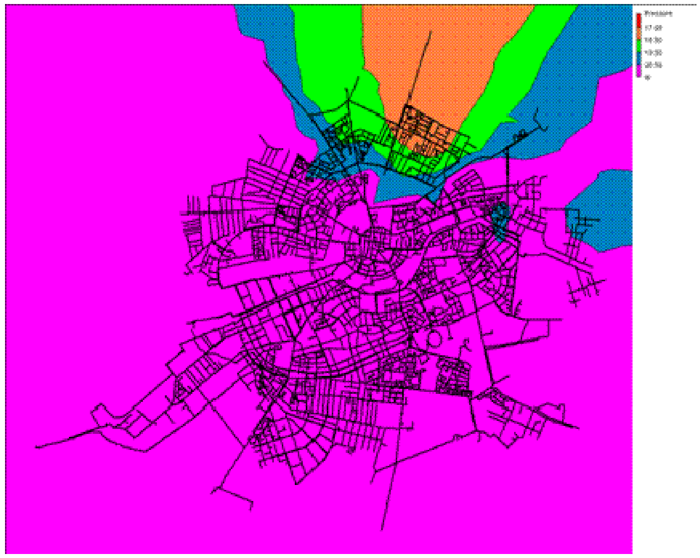

Fig. 9 Distribution of the pressure in the distribution system after 52 hours

In the figures no.8 and no.9 are evidenced the water velocities from the distribution system. These velocities are correlated with the concentrations of the residual chlorine after 52 hours and respectively 68 hours.

5. CONCLUSION

The case study highlights the fact that in the portions in which the flow velocities decrease and the water stagnate for more than 7 days the residual chlorine will decrease actually under the limits imposed by the Romanian standards (0.5 mg/l). For a safe disinfection, the residual chlorine in potable water must be at least 0.3 mg/l. The chlorine process is easy to be applied but must be carefully controlled because if the dose is more than 0.3 mg/l gaseous chlorine emanation will appear.

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