Research Article

The effect of age and material on the deterioration of chlorine separation in the water supply network using the qualitative–hydraulic model EPANET (II)

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Abstract

According to international and domestic standards, the concentration of free chlorine remaining in each node must be between certain values. In this way, the health of the water is guaranteed. Water sources are chlorinated after treatment and enter the water distribution network. Injected chlorine is reduced in this path by reacting with materials in the water (mass deterioration) and the distribution network pipe wall (wall decay). Meanwhile, wall deterioration is a function of the age and material of the pipe. This study evaluated the pipe material parameter among the group of PVC and cast iron pipes. Also, to investigate the effect of age, the amount of residual free chlorine distribution in cast iron pipes with ages of zero, 10, 20, and 30 years was qualitatively hydraulically simulated. A comparison study showed that the maximum difference in free chlorine concentration in different genera is 17.82% and at different ages is 34.71%.

Introduction

The free chlorine remaining in the water supply networks guarantees the quality and health standards of drinking water. However, it should be noted that this factor does not exist in equal parts in all parts of the network and has fluctuations. In some parts of the network, the amount of chlorine is too much and produces taste and smell, and in other parts of the network, the amount is less than the allowable limit, leading to an increased risk of epidemics of microbial diseases. The phenomenon of free chlorine reduction in water supply networks is referred to as chlorine decay. Several factors and reactions such as the presence of soluble and suspended organic matter, iron, manganese, and ammonia mineral compounds, as well as various microorganisms and algae compounds,

lead to changes and reduction of free chlorine concentration in the water supply network. Chlorine degradation in two general cases, mass degradation, and wall degradation lead to a decrease in free chlorine concentration along with the water supply network. Mass decay is a function of the temperature and matrix of materials in the fluid, while the deterioration of the wall depends on the age and material of the pipe. Qualls and Johnson [1] and Dominguez, et al. [2] investigated the reaction between chlorine and organic compounds in water. In this study, fluoric acid was used for the experimental simulation of organic matter in water and groundwater, respectively. The results of the study by Qualls and Johnson [1] showed that the reaction lasts only five minutes, which reacts quickly and then slowly in the first minute. Hence, for the first time, the rates of rapid and slow decay for the chlorine reaction were

separated. Haas and Karra [3] considered water as a complex matrix and analyzed, studied, and evaluated the traditional behavior of chlorine with all materials in this matrix. The study is considered as one of the pioneers in this field, because it led to the creation of five practical models in the field of chlorine mass degradation. The accuracy of the models obtained in this basic research was confirmed by other researchers in the following years. Gravman, et al. [4] also researched chlorine mass degradation. The results of these experiments showed that chlorine, in reaction with organic matter in water, usually follows first-degree reactions. Wable, et al. [5] compared the rate of chlorine decay in tubes and glass. The results of their research showed that the rate of chlorine decay in the tube is several times the same in the glass. In another study, Hunt, et al. [6] and McGrath, et al. [7] studied the rate of chlorine degradation in the water supply network. In addition, the research of Clark, et al. [8] showed that the amount of chlorine remaining during the day varies and in different places of the water supply network depends on the flow path and retention time of water in the network. Rossman, et al. [9] studied chlorine decay with a mass transfer approach across the network. The researchers in this study stated that the rate of chlorine deterioration in the mass and wall of the pipes follows the first degree. Cordoba [10] used four-year quality information and data to predict the quality parameters of the water distribution system in Czech Republic. He used the multiple regression method and EPANET qualitative model to predict. Georgescu and Georgescu [11] calculated chlorine degradation in an urban distribution network with a population of 50,000. In this study, it was found that the reaction of chlorine in the fluid mass and the wall of the pipes follow the first degree. The results of this study showed that the rate of chlorine degradation in the network is proportional to the flow rate and consumption in the network. This research also intends to evaluate and investigate the effect of age and pipe material on chlorine wall decay in the water supply network using qualitative-hydraulic simulations.

Materials and methods

The network understudy

The network required for the study in this study, the Brains-Polynes network with 36 nodes, a mixture, and a pumping station is described in Figure 1. It is worth mentioning that the maximum height code in this network is related to the mixture with a height of 70.5 meters and the minimum height is related to node number (1) with 15.01 meters.

In this part of the study, for each node, Demand Assignment operations have been performed according to Figure 2. The studied network has pressure fluctuations overtime during the consumption pattern, which is shown in Figure 3.

Finally, it should be noted that in the process of qualitative-hydraulic simulation of this network, the value of mass degradation coefficients is constant and is considered equal to zero, respectively. The consumption pattern of the mentioned network is also shown in Figure 4.

Qualitative-hydraulic simulation

The reaction between chlorine and the pipe wall of the distribution and water transmission network, which leads to a decrease in chlorine concentration, refers to wall decay. As can be seen in relation to number (1), there is a direct relationship between application level (surface to volume ratio), mass transfer coefficient (KW), and chlorine wall decay rate.
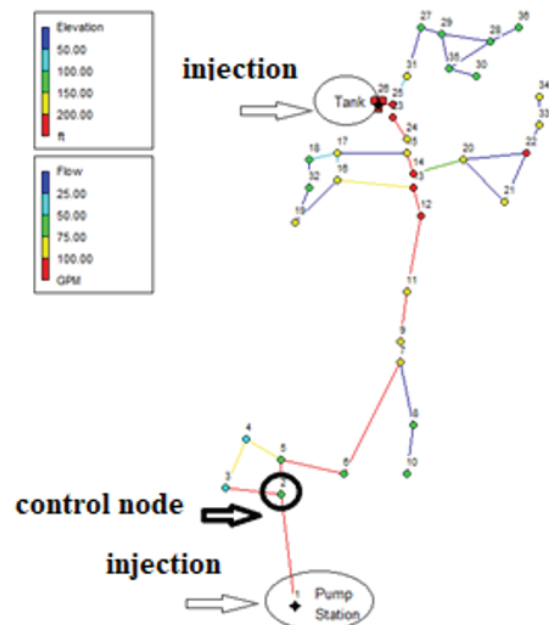

Figure 1: An overview of the shape of the Braine-Polynes network based on the height code of the nodes in the network.
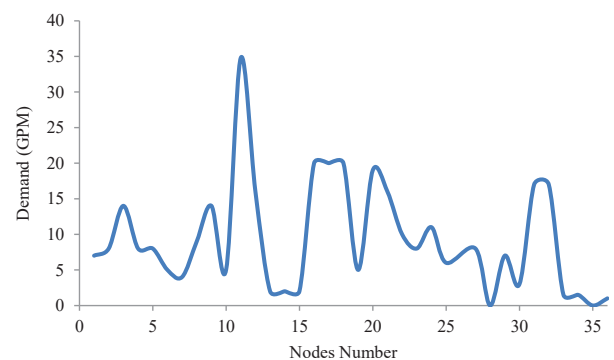

Figure 2: Water consumption per node of Braine Plins Network (GPM).
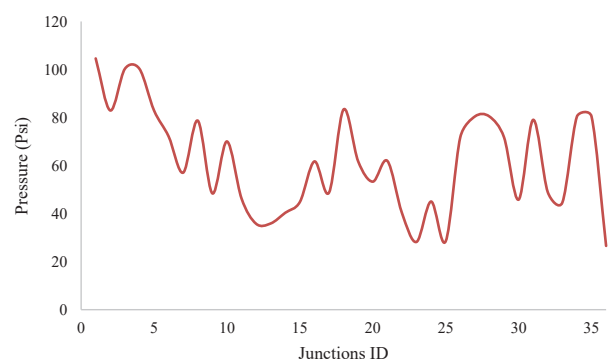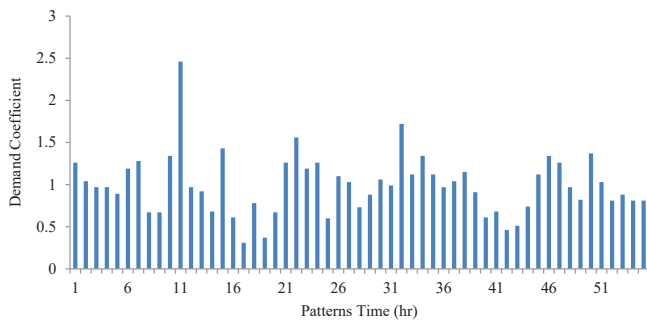

Figure 3: Pressure of each node of the Pliny Braille network (Psi).

Figure 4: The 55-hour water consumption pattern coefficients in the Brains-Polynes network were studied.

$$\frac{dC}{dt} = \frac{A}{V} k_W C^n \tag{1}$$

Many researchers [12,13] have emphasized that the degree of wall decay reaction is primary.

$$\frac{dC}{dt} = \frac{2k_W k_f C}{R(k_W + k_f)}, k_f = sh\frac{D}{d} \tag{2}$$

In relation to number (2), the parameters kw, kf and R represent the wall reaction coefficient (dependent on the pipe material), the mass transfer coefficient, and the pipe radius, respectively. The mass transfer coefficient (kf) is a function of the ratio of the diffusion coefficient of chlorine particles $\left(D = 1.21 \times 10^{-5} \frac{cm^2}{s} \ for-free \ \mathrm{Re}\ sidual-chlorine, Rossman(1994) \right)$ to the diameter of the tube (d) and the dimensionless number of Sherwood (Sh); The Sherwood number is also calculated for slow flow ($R_e \le 2000$) according to Equation (3).

$$Sh = 3.65 + \frac{0.0668(\frac{d}{L})S_c R_e}{1 + 0.04((\frac{d}{L})S_c R_e)^{\frac{2}{3}}}$$

$R_e \to \mathrm{Re}\ ynold's - Number$

$S_c \to Schmidt's - Number$

$$S_c = \frac{v}{D}, D(diffuvisity) \& v(kinematic-vis\cos ity) - Ed \ var \ d(1976) \tag{3}$$

It is worth mentioning that the mentioned qualitative–hydraulic simulations will be performed in the environment of the EPANET (II) model. To observe the changes in the concentration of free chlorine remaining in the time series, node (2) was selected as the control node. Also, the qualitative behavior of all nodes at peak consumption was examined.

Age and material of pipes

In this part of the study, the effect of age and material

of distribution network pipes on chlorine wall decay will be evaluated. In the first step, the analysis of the network with PVC and cast iron materials will be evaluated, the characteristics of their wall degradation coefficient are stated in Table 1.

In this section, the effect of different ages of cast iron pipes in the water supply network will be examined; The details of their coefficients are presented in Table 2.

Results and discussion

As shown in Figure 5, PVC pipes have less deficiency than cast iron pipes. Statistical analysis shows that in the time series, you can have the maximum consumption pattern of this difference between cast iron and PVC in the control node (node number (2)) equal to 14.7%.

The values of the difference in the concentration of free chlorine remaining in the various nodes of the Brains–Polynes network (at peak consumption) are shown in Figure 6. The maximum difference values between cast iron and PVC are related to node number (22) with a value of 17.82%.
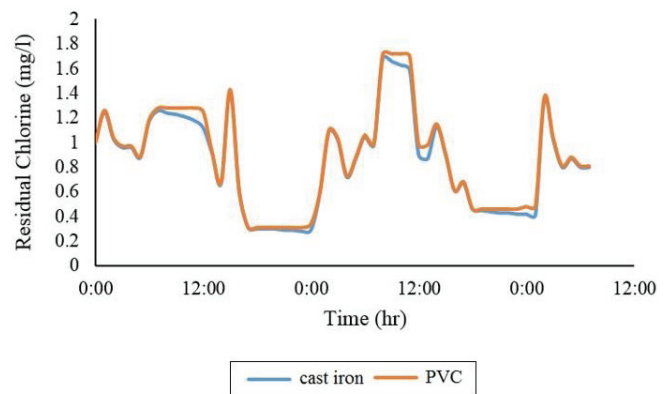
Then, the effect of age of cast iron pipes on the decay of chlorine wall was evaluated, which is described in Figure 7. Examination of the time series of consumption pattern in the control node showed that the maximum difference in free chlorine concentration between the newest and oldest cast iron pipe is 19.5%.

Table 1: Hazen-Williams coefficient and wall decay according to AWWA

Tube age	Hazen-Williams coefficient	Wall deterioration coefficient (m / day)	Pipe material
0	130	0.1524	Cast iron
0	150	0	PVC

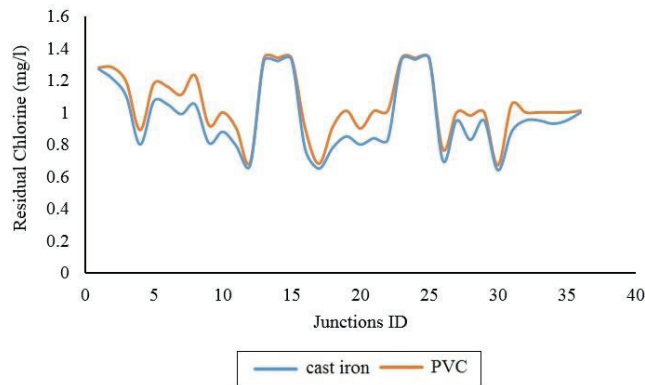**Table 2:** Hazen-Williams coefficient and cast iron pipe wall decay at different ages according to AWWA.

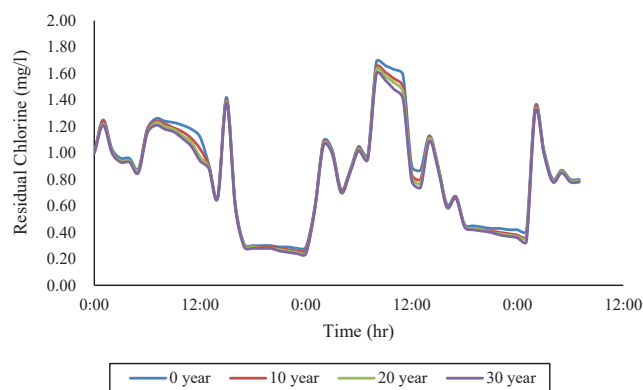| Hayes coefficient - Williams	Wall deterioration coefficient (m / day)	Tube age
130	0.1524	0
110	0.3626	10
95	0.52	20
82	0.715	30

Figure 5: Comparison of free chlorine residues in PVC and cast iron networks - control node time series.

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Also, the results showed the difference in the concentration of free chlorine remaining in different nodes (at peak consumption); In the case of maximum node number (22), there is a 34.71% distance between the newest and the oldest pipe. All these differences are presented as the concentration gap under the influence of tube age in Figure 8.
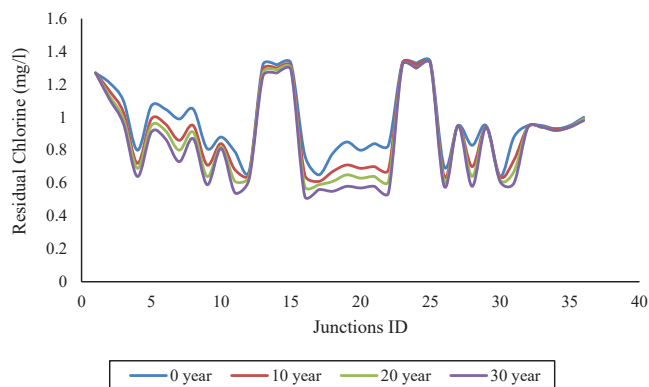
Comparison of the percentage difference between the age and material of the pipe shows that the age of the pipe has a greater effect on the decay of chlorine wall than its material. Some studies have recommended a specific type of

Figure 6: Comparison of free chlorine remaining in all nodes of PVC and cast iron networks - peak consumption time.

Figure 7: Comparison of residual free chlorine at different pipe ages - control node time series.

Figure 8: Comparison of free residual chlorine of all nodes at different pipe ages - peak consumption time.

pipe material. For example, in Learbuch, et al. [14] research, PVC has shown better performance than other pipe materials in the water distribution network. These studies have also been performed about other materials of pipes; for example, copper and composite plastic in a pilot-scale water distribution network has been examined, and chlorine has decreased the microbial numbers successfully in the water of composite plastic pipes [15,16]. When comparing to previous studies, the influence of pipe material has been tested on the occurrence and persistence of the target microorganisms that comparing iron, cement, and PVC pipe materials in different ages were fed either chlorinated water, and the influence of pipe material and age of pipes have become apparent to low disinfectant residual [5,17,18–25].

All statistical evaluations are done by descriptive models.

Conclusion

The free chlorine remaining in the water supply networks ensures the microbial and to some extent chemical quality of the water. Therefore, predicting and investigating the factors affecting chlorine degradation is of special importance. Chlorine mass decay occurs within the water matrix and is a function of temperature and constituents in the water. This is while the deterioration of the wall is a function of the age and material of the pipe. In the first step, this study investigated and evaluated the effect of cast iron and PVC pipes on chlorine wall deterioration and showed; In the conditions of maximum difference of chlorine concentration between these genera reaches 17.82%. Next, we simulated the effect of pipe age in the cast iron sample. The results of this section also showed a maximum difference of 34.71% of the remaining chlorine concentration between the newest (zero years) and the oldest (30 years) age of the tube. Finally, the simultaneous study and comparison of the effects of age and material indicate the greater importance of pipe age in chlorine wall decay.

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