CHLORINE DECAY IN WATER DISTRIBUTION SYSTEMS CASE STUDY – LOUSADA NETWORK

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ABSTRACT
Application of first-order kinetics to model chlorine decay, using EPANET software on a real network, for calibration.

INTRODUCTION

The objective of any water distribution system is to make water available to the consumer in proper quantity and pressure, with acceptable quality in terms of flavour, odour, appearance and sanitary security.

Preserving the water quality throughout the distribution system is, therefore, one of the most challenging technological issues for suppliers. This is not an easily attainable objective, mainly because of the distribution system's complexity and dynamism with respect to building materials, element diversity and other properties variability.

Drinking water has been disinfected since the beginning of the nineteenth century, when one discovered that microbiological contamination risks by water born diseases, namely cholera or typhoid fever, decreased drastically when disinfectants were used.

There are several disinfection methods which can be applied to high water flows. They can be divided into three main groups:

- UV radiation;
- Ozone;
- Chlorine.

The first two groups do not generate significant Disinfection By-Products (DBP's) nor interact significantly with the water they are supposed to disinfect. Despite their efficient disinfecting qualities, they do not guarantee a long-term disinfection, up until the water reaches the consumer.

Chlorine disinfection, on the other hand, presents the advantages of efficiency and durability.

The concept of Residual Concentration of Disinfectant is associated with disinfection durability. In fact, so as to guarantee the water supply system's disinfection, we need a residual concentration disinfectant to prevent recontamination by pathogenic or indicator micro-organisms, which can originate in the biofilm formed inside the system, as well as in negative pressure areas (created by pipe cracks, fissures, etc.).

There is, however, a problem when water distribution systems have considerable proportions. In a phenomenon known as chlorine concentration decay, chlorine residual concentration disappears along the system.

Knowing the physico-chemical aspects behind chlorine decay is in order if we are to develop a strategy capable of disinfecting a water supply system and, at the same time, preserving water quality until the point of use, without using more disinfectant than necessary. In this sense, mathematical modelling of the decay is essential to correctly project new systems or make changes in existing ones.

MECHANISMS OF CHLORINE DECAY

The loss of chlorine residual concentration along the water distribution system is processed in three separated mechanisms:

- Chlorine reactions in bulk fluid;
- Chlorine reactions with pipe and other system element's walls.
- Natural evaporation.

If, ideally, the chlorinated water was pure and the material of the pipes was inert, the only mechanism leading to the decay would be that of natural evaporation, especially in particular areas of the distribution system, namely reservoirs and other free surface flows.

MATHEMATICAL MODELLING OF CHLORINE DECAY

Mathematical modelling of chlorine decay along the water supply system is a problem whose solution is not yet absolutely mastered. Decay simulation conducted within EPANET takes into consideration the phenomena of chlorine reaction with chemical species at bulk fluid and with pipe walls. The contribution of bulk fluid is introduced into the software by means of a first order kinetics constant, K_b. The contribution of wall reactions is introduced into the software through another constant K_f, whose meaning is more complex.

To assure the correct use of the water quality simulator, incorporated in the EPANET, one must conduct a model calibration process. This consists of attributing the correct values to K_b and K_f coefficients. In most cases, model calibration is conducted *a posteriori*, altering parameter values in order to obtain, in the model, values that match real ones. Nevertheless, ideal calibration must be conducted by taking samples of water and by studying pipelines nature. These samples allow us to predict the real K_b and K_f values.

Within this study, we have conducted a laboratory determination of the K_b value of the water supplied to the southern Lousada municipality, a network supplied by the Lodares water - storage tank [1]. The value of K_f will be determined based on local free residual chlorine measurements.

The EPANET software models the chlorine decay through a first order kinetic law. This kinetic law takes the form of an equation which allows us to calculate the concentration of chlorine in the water, C, throughout the transportation time, t. To calculate this, we need to know the chlorine concentration at the beginning of the transportation, C_o.

$$C = C_o \cdot \exp(-K_b \cdot t) \tag{1}$$

The adjustment coefficient, K_b, is calculated based on laboratory results of analysis conducted in batch reactors.

It is possible for us to observe how chlorine decays over time by means of sealed container analyses of a particular water sample. We can infer the value of K_b by adjusting the chlorine concentration curve over time to equation 1, by recurring to the least squares method.

CASE STUDY

This work is based on the study of part of a real distribution system, in the municipality of Lousada and is supported by the 2.0 version of the EPANET simulator so as to illustrate the process of calibrating and using the water quality model.

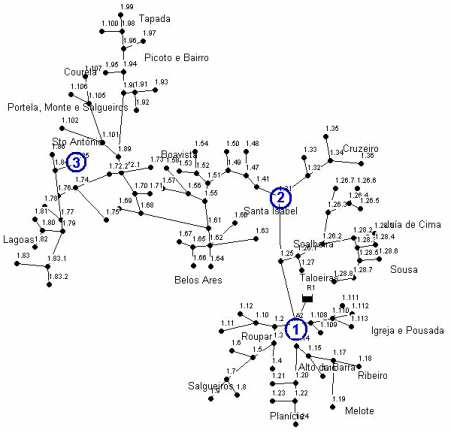


Fig. 1 – Southern Lousada water supply system – Lodares Water – Storage Tank [1]

After taking a sample of water being distributed by the referred water supply system, we implemented the procedure described in the following diagram:

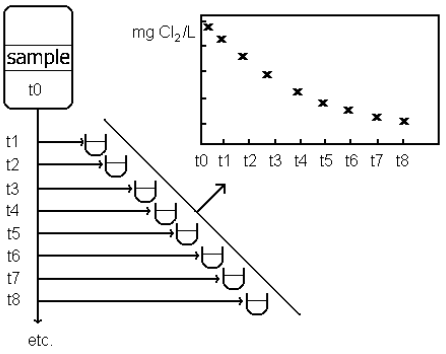


Fig. 2 – Diagram of laboratory method used in calibrating K_b.

This method has shown the following results:

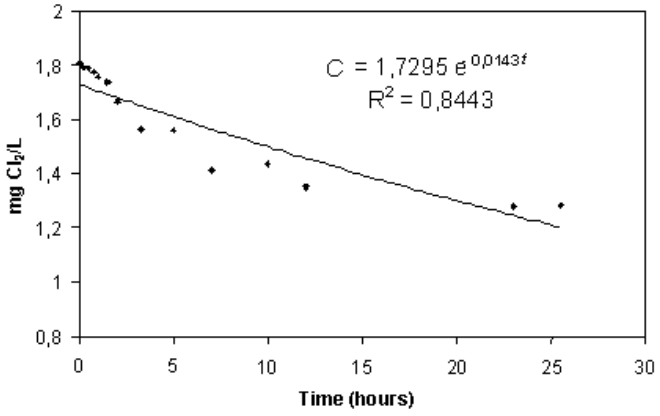


Fig. 3 – Chlorine decay at bulk fluid and respective first order adjustment.

We have determined that the value of K_b is **-0.0143 hour^{-1}**, which corresponds to **-0.3432 day^{-1}**.

Using EPANET

Hydraulic modelling

To conduct a quality simulation in a given distribution system, one must have a hydraulic model on which to apply the EPANET quality model.

The hydraulic model supporting this study is developed in "*Rede de Abastecimento de Água do Sul do Concelho de Lousada: Rede afecta ao reservatório de distribuição de Lodares"*[1].

Water quality modelling

Since the K_b coefficient was determined in laboratory, it is directly introduced into the software.

The K_b coefficient is denominated as bulk reaction coefficient and will have the value of -0.0143 hour^{-1}. The value must be preceded by a minus sign in order to indicate a disappearance coefficient.

We will not enter the value of K_f at this phase, because its calibration will occur later.

The simulation's preliminary data can be presented by EPANET in the shape of a map of concentration isolines. In a first approach, we only used the K_b value to characterize the chlorine decay, getting the data presented in Fig. 4.

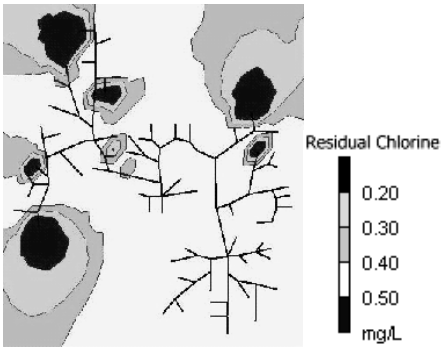


Fig. 4 – Concentration tie-lines of chlorine throughout the system (12 hours)
K_b = -0.0143 hour^{-1}; K_f = 0.00 ft s^{-1}

As we can see in Fig. 5, introducing a K_f value considered frequent [2], alters the concentration tie-lines map significantly. In this case, the chlorine reaction with pipe walls contributes 80% to total chlorine decay values.

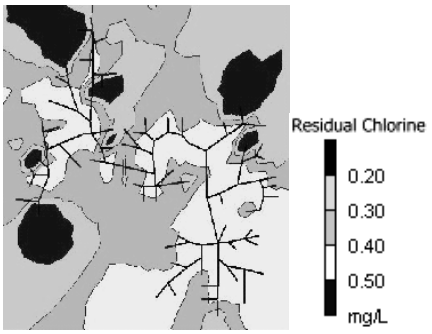


Fig. 5 – Concentration tie-lines of chlorine throughout the system (12 hours)
K_b = -0.0143 hour^{-1}; K_f = 0.002 ft s^{-1}

In Fig. 1 we have the nodes where residual chlorine analyses were conducted. Samples were taken on nearby, intermediate and distant locations, in relation to the reservoir.

Fig. 6 represents the result of K_f coefficient calibration through the trial-error method. The charts on

the left of the table represent results prior to K_f calibration, those on the right represent results after K_f calibration. K_f value was found to be **– 0.007** ft.s^{-1}.

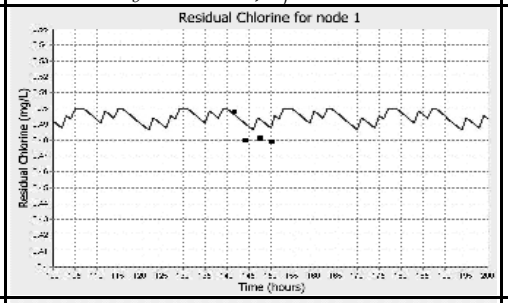
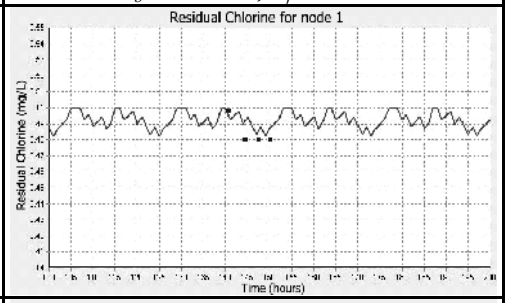
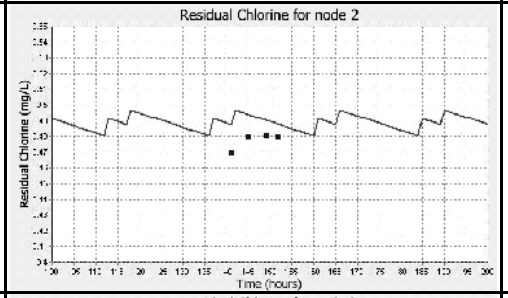
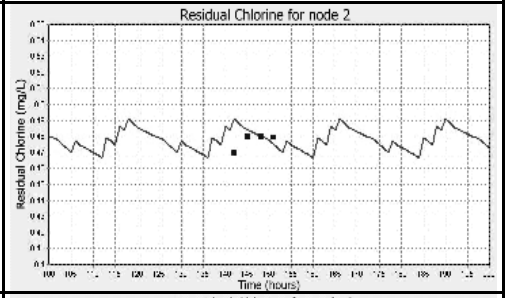
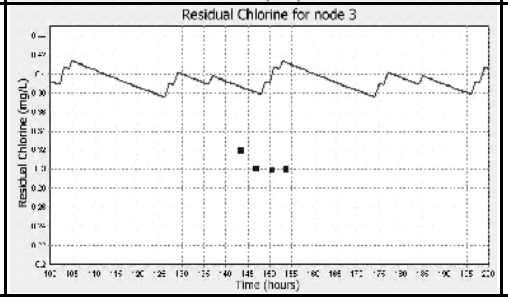
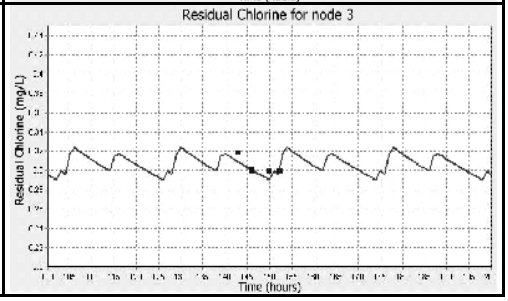
	K_b = **-0.0143**; K_f = **-0.002**	K_b = **-0.0143**; K_f = **-0.007**
Node 1		
Node 2		
Node 3		

Fig. 6 – Simulation results for nodes 1, 2 and 3, before and after K_f calibration

Fig. 7 stands for the final map of concentration isolines.

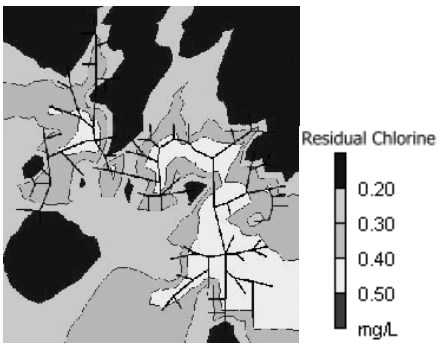


Fig. 7– Final map of concentration isolines (12 hours)

CONCLUSIONS

This paper stresses several points, one of which is that pipe wall reaction contribution is more significant than that of bulk fluid reactions. One must bear in mind that we are dealing with a rechlorination station and that, at this stage, water has already lost most of its chlorine consumer constituents in it's first chlorination step.
Although there are other chlorine decay models, from which the parallel first order and the *n*-order models stand out, the EPANET-incorporated first order model was found to be satisfactory in terms of rechlorination stations.
EPANET, as well as any other first-order model-supported software, can be optimised as a tool if we are to conduct studies correlating basic water properties, such as BOD, COD, TOC, Fe^{2+} concentration, temperature, etc., with K_b typical values.
Also, it will be possible to relate pipeline age and material with K_f value.
Once we have a hydraulic and water quality model set up and properly calibrated, we can rely on its predictions when planning changes to its base structure.

ACKNOWLEDGMENTS

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REFERENCES

[1] - "*Rede de Abastecimento de Água do Sul do Concelho de Lousada: Rede afecta ao reservatório de distribuição de Lodares*"; Ramos, J.; FEUP, 2002.
[2] - "*Controlo do Residual de Cloro em Sistemas de Transporte e Distribuição de Água*"; Vieira, P.; Coelho, S.T.; Praça. P.; LNEC, 2001.