Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Study of the performance of disinfection with sodium hypochlorite on a full-scale sewage treatment plant

ARTICLES doi:10.4136/ambi-agua.2652

Received: 29 Sep. 2020; Accepted: 13 Oct. 2020

Maria Rosaria Boni[1]; Sabrina Copelli[2]; Massimo Raboni[3*]

[1]Department of Civil, Constructional and Environmental Engineering (DICEA). University of Rome "La Sapienza", Piazzale Aldo Moro, n° 5, 00185, Roma, Italy. E-mail: mariarosaria.boni@ing.uniroma1.it
[2]Department of Science and High Technology. University of Insubria, Via Ravasi, n° 2, 21100, Varese, Italy. E-mail: sabrina.copelli@uninsubria.it
[3]PhD in Civil Engineering. University of Pavia, Corso Str. Nuova, n°65, 27100, Pavia, Italy
*Corresponding author. E-mail: massimo.raboni@gmail.com

ABSTRACT

A full-scale sewage treatment plant was investigated to assess the performance of the disinfection stage. Sodium hypochlorite was used as a disinfectant agent and the process efficiency was evaluated by E.coli removal. The research took place over a period of two years in order to evaluate the effect of retention time (t) and residual chlorine (Cr) under different seasonal conditions. The effectiveness of *E.coli* removal with sodium hypochlorite proved to be strictly dependent on the factor C_R t (product of residual chlorine with the contact time). The regression line of the experimental points was, on the whole, well comparable with the model proposed by Collins, especially in the field of C_Rt lower than 30 mg L^{-1} min.

Keywords: disinfection, *Escherichia coli*, sewage treatment plants.

Estudo do desempenho da desinfecção com hipoclorito de sódio em uma planta de tratamento de esgoto em escala real

RESUMO

Uma estação de tratamento de esgoto em escala real foi investigada para avaliar o desempenho da etapa de desinfecção. Hipoclorito de sódio foi utilizado como desinfetante e a eficiência do processo foi avaliada pela remoção de E. coli. A pesquisa durou dois anos para avaliar o efeito do tempo de retenção (t) e do cloro residual (C_R) em diferentes condições sazonais. A eficácia da remoção de E. coli com hipoclorito de sódio provou ser estritamente dependente do fator C_Rt (produto do cloro residual com o tempo de contato). A linha de regressão dos pontos experimentais é, em geral, bem comparável ao modelo proposto por Collins, especialmente no campo de C_Rt inferior a 30 mg L^{-1} min.

Palavras-chave: desinfecção, *Escherichia coli*, estações de tratamento de esgoto.

1. INTRODUCTION

The microbiological analysis of water and wastewaters commonly refer to micro-organism indicators. Fecal coliforms have been used for many years, but more recently E.coli was taken as a more specific indicator, thus becoming the reference parameter for much international and local legislation.

Sewage treatment plants play an important role in the removal of typical pollution parameters such as BOD_5, COD, Total Nitrogen (TN) (Luciano *et al*., 2012; Viotti *et al*., 2014), total phosphorus (Ptot) and suspended solids (SS), but they are also very effective in removing microbiological pollution. They also remove some types of drugs (Chiavola *et al.*, 2019). The scientific literature is full of information on total and fecal coliforms in sewage and on their removal efficiency. Fecal coliforms are detected in raw sewage in the range of 10^6–10^8 100 ml^{-1}, while E.coli concentration is in the range 5.5-7.0 10^6 100 ml^{-1} (Tchobanoglous *et al.*, 2003; Raboni *et al.*, 2016; Demir, 2016). Sewage treatment plants can remove these indicators by 90-98%, and an effective additional removal of up to 99.999% can be achieved by a final disinfection process. Currently the most advanced treatment plants use strong disinfectant agents such as ozone, UV rays, peracetic acid, and others (Castro Ribas and Fortes Neto, 2008; de Oliveira Pereira *et al*., 2011; Amin *et al.*, 2013; Verma *et al.*, 2015; Barreto Camilo Junior *et al.;* 2019; de Almeida Soares Oliveira *et al*., 2019;) but the traditional sodium hypochlorite is still the most widely used all over the world due to its low cost and ease of use. We investigated a full-scale sewage treatment plant located in an area north of Milan, Italy. As shown in Figure 1, the plant performs biological denitrification and oxidation-nitrification followed by phosphorus precipitation. It is a very well-studied, widely applied process (USEPA 1997; 2010; Capodaglio *et al*., 2015; Copelli *et al*., 2015; Raboni *et al*., 2015; 2016; 2017; Torretta *et al*., 2013; 2014; Viotti *et al*., 2016). The plant is also equipped with a final disinfection unit (open contact chamber with baffles) to which NaClO (solution 15% as Cl_2) is dosed.

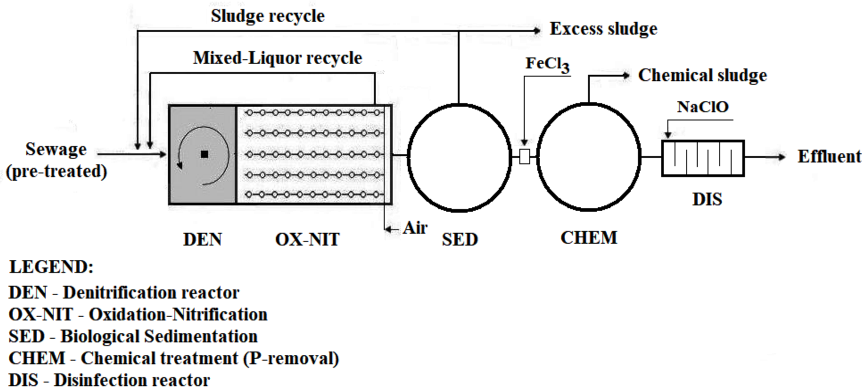

Figure 1. Simplified layout of the sewage treatment plant.

The correlation between the disinfection performance with the factors contact time t and residual chlorine CR is cited several times in the scientific literature.. Among these, the research recently carried out on 6 full-scale plants deserves particular mention (Raboni *et al.*, 2016). The present research has been developed in a similar way, but over a much longer period of time (2 years) so as to also include the possible effects of the different seasons and related climatic conditions.

2. MATERIALS AND METHODS

2.1. The wastewater treatment plant

Table 1 shows the main features of the plant. Of course, the retention times reported represent the average values, as they vary significatively over time because of the fluctuations of the wastewater flow rate (daily and seasonal fluctuations).

Table 1. Characteristics of the sewage treatment plants.

Flow rate (m^3 d^{-1}) *	Capacity (eq. inh.) **	Av. Retention time***		
		Biological Denitrification (h)	Biological Oxidation-Nitrification (h)	Disinfection (min)
33,000	80,000	4.5	14.1	25

* referred to average flow rate in dry weather
** by assuming 60 g BOD_5 d^{-1} inh^{-1}
*** referred to average flow rate in dry weather

The performance of the plant is shown in Figure 2, by the parameters BOD_5, COD, Suspended Solids, TKN, NO_3-N and P. Statistical data are referred to mean values and relative Standard Deviation (SD) of both raw sewage and treated effluent. The plant runs in full compliance with the discharge limits issued by Italian legislation: BOD_5= 25 mg L^{-1}, SS= mg L^{-1}, TN= 10 mg L^{-1}, P_{tot} = 1 mg L^{-1}. As to E.coli the average values in raw sewage and in the final effluent after disinfection are 5.9 10^6 100 mL^{-1} and 2,600 100 mL^{-1} (SD = 480 100 mL^{-1}) respectively. Always with reference to E.coli the discharge limits issued by Italian legislation is E.coli = 5,000 CFU 100 mL^{-1}.

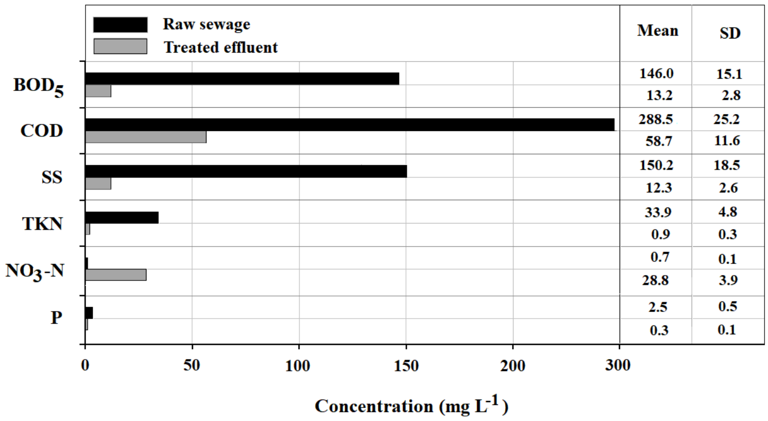

Figure 2. Statistical data of the plant performance referred to BOD_5, COD, Suspended Solids, TKN, NO_3-N and P.

2.2. Sampling and analysis

The investigation lasted 24 months during which 48 sampling campaigns were carried out. The sampling points were at inlet and outlet of disinfection chamber and E.coli in samples was enumerated by the membrane filtration technique and the results were expressed in Colony Forming Units (CFUs) per 100 mL^{-1}. At the same time, various operating data of the plant were collected, among which wastewater flow rate, temperature, pH and residual chlorine at the end of disinfection. The retention time in the disinfection reactor was calculated in correspondence with the corresponding flow rate.

Sampling and analyses were carried out in accordance with the official analytical methods of Italian legislation, issued by the IRSA-Institute for Water Research of the Italian National Research Council and APAT-Agency for the protection of the Environment and Technical Services (IRSA and APAT, 2003)

The data collected with this analytical campaign were used to verify the correlation of the E.coli removal efficiency with C_Rt (product of residual chlorine at the end of the disinfection reactor with the contact time). Thus, a total of 96 instantaneous samples were collected for the E.coli count.

The residual chlorine was detected with a portable HI Series HI711 analyzer using a fixed wavelength LED and silicon photodetector, in the range 0-3.00 mg L^{-1}, resolution= 0.01mg L^{-1}. These measures were compared with the residual chlorine amperometric analyzers mounted in line.

In order to make the graphic representation easier, the disinfection performance was evaluated by the efficiency ratio Eo/E, where Eo represents the E.coli concentration at the inlet of disinfection and E at the outlet.

3. RESULTS AND DISCUSSION

In Italy, the disinfectant dosage is set to obtain a concentration of E.coli in the final effluent of less than 5000 CFUs 100 mL^{-1} (recommended limit according to Italian legislation). Thus, the dosage normally varies in the range of 3-6 mg L^{-1} (as Cl_2), depending on the plant. For instance, higher dosages are necessary in plants with still rather high values of TKN and SS in the treated effluent. Conversely, in plants with a high efficiency of nitrification and of suspended solids removal, smaller doses are required. In this specific plant, due to the strong nitrification and to the polishing effect of tertiary treatment, the NaClO dosage was limited in the range 1.5-3.5 mg L^{-1} (as Cl_2).

Figure 3 shows the experimental correlation between the efficiency ratio of disinfection Eo/E with the product of chlorine residual C_R with the contact time t. The regression line of the experimental points demonstrates a logarithmic-like growth, i.e., with a progressively higher gradient at increasing values of the product C_Rt. In reality, as shown in the Figure 3, the best interpolation of the experimental points is given by a third degree polynomial equation with a correlation factor R^2=0.8923. This value of R^2 and the 95% confidence interval represented in the Figure 3 allow a good level of reliability of the regression line (especially at low-medium values of C_Rt). But, at the same time, it should be noted that this experimentation did not highlight the specific role of temperature, which could be more than appreciable considering the wide range assumed in the long experimentation period (T=12-22°C). In fact, the scientific research has not yet adequately investigated the influence of temperature which, when properly considered, could lead to an improvement in the level of reliability of the experimental correlation represented in Figure 3.

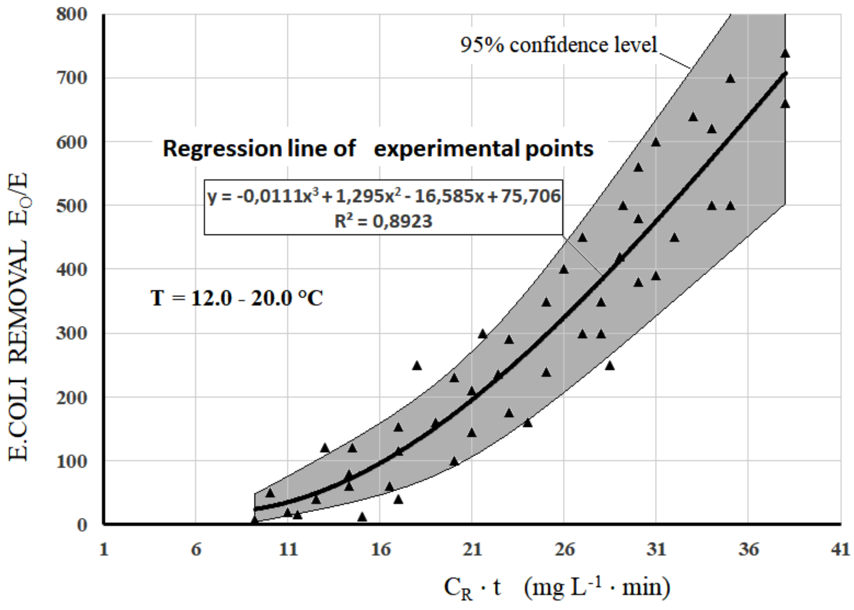

Figure 3. E.coli removal by disinfection with sodium hypochlorite, as a function of C_Rt (product of chlorine residual with contact time).

The choice of the efficiency ratio Eo/E allows a good comparison of the experimental results with two of the most commonly used models to describe the performance of the chlorine disinfection of secondary effluents (Tchobanoglous *et al*., 2003; White, 1999; 2010; Collins, 1970; 1972):

- Collins model $Eo/E = (1 + 0.23\ C_R t)^3$
- The White model $Eo/E = [(C_R t)/b]^n$

where the typical value of the constants, for fecal coliforms are b=3.0 and n=2.8.

Figure 4 shows this comparison, which proves that the experimental curve fits well the Collins model at $C_R t$ values of lower than about 30 mg L^{-1} min. Figure 5 shows in detail the deviation of the experimental curve from the two models. The deviation is defined as the percentage difference between the Eo/E values of the models compared to those of the experimental curve, at different values of the product $C_R t$. It can be observed that within the range $C_R t$ =20-30 mg L^{-1}min the deviation of the experimental curve from the Collins model is lower than about 10%. However, at values greater than 30 mg L^{-1}min, this percentage tends to approximate 20% deviation. On the contrary, the deviation of the experimental curve from the White model is always higher than 10%, thus making them hardly comparable.

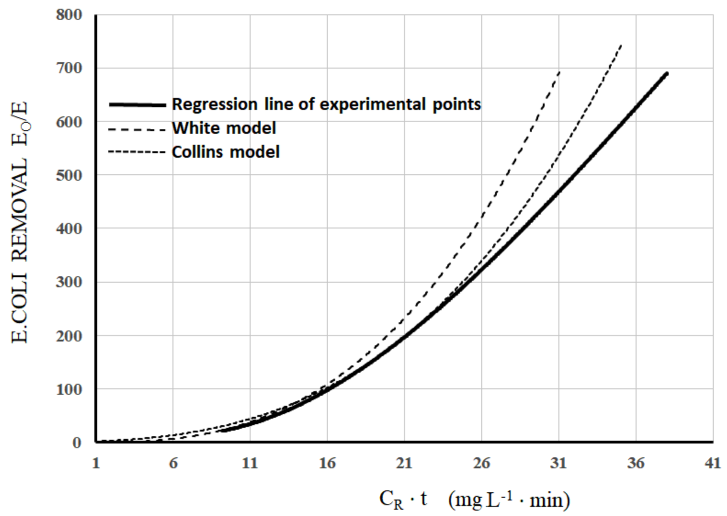

Figure 4. Comparison of the experimental curve with the Collins and White models.

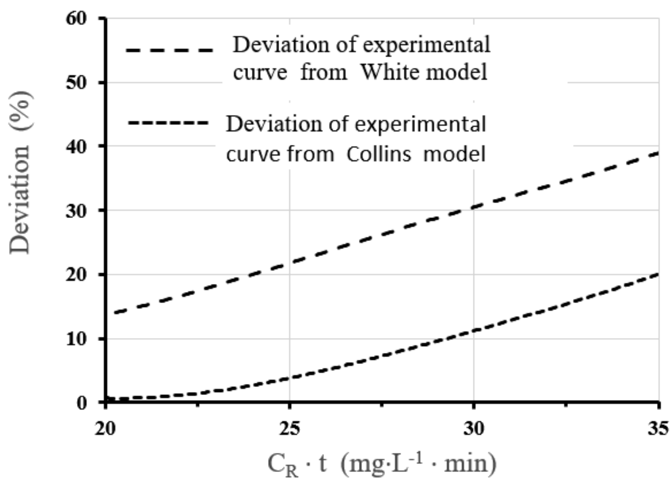

Figure 5. Deviation (%) of the experimental curve from the White and Collins Models.

With regard to what is illustrated in the last two figures, attention must be focused on an important aspect: the absence of the temperature factor in the two models examined. In reality, the influence of this factor on the efficiency of disinfection has not yet been adequately studied, although it is recognized that it affects all types of chemical and biochemical kinetics. Thus, it is likely that in sewage treatment plants with significant variations in temperatures the simulation models should be implemented. Furthermore, the deviation in efficiency among the curves could be partially explained by the above considerations.

4. CONCLUSIONS

The disinfection treatment with sodium hypochlorite in a full scale sewage treatment plant was investigated for two years in order to highlight the role of the two factors residual chlorine C_R and contact time t. In this research, the disinfection efficiency was represented by the efficiency ratio E_O/E (ratio of E.coli at disinfection inlet and outlet, respectively)

The experimental results demonstrate the key role of the factor C_Rt (product of the residual chlorine with the contact time). The regression line of the experimental points shows a progressively higher gradient of Eo/E at increasing values of the product C_Rt. The line could be represented by a polynomial equation with a correlation factor R^2=0.8923. The results of the research show that the experimental curve tends to fit well with the Collins model $Eo/E = (1 + 0.23\ C_Rt)^3$ at C_Rt values below about 30 mg L^{-1} min. In order to achieve further advances in this field, it is recommended that further in-depth studies on the concomitant role of temperature be conducted. The information gleaned would lead to the development of more complete and reliable models for simulating the disinfection process.

5. REFERENCES

AMIN, M.M.; HASSAN, H.; ASHEM, I H.; BOVINI, A.M.; YUNG TSE HUNG, Y. A review on wastewater disinfection. **International Journal of Environmental Health Engineering**, v. 2, n. 1, p. 1-9, 2013. https://dx.doi.org/10.4103/2277-9183.113209

BARRETO CAMILO JÚNIOR, O.; SANDRI, D.; RODRIGUES DE ALENCAR, E.; FERRAZ HEBLING, L. Ozonation improves physical attributes in domestic sewage effluent. **Revista Ambiente & Água**, v. 14, n. 2, 2019. https://dx.doi.org/10.4136/ambi-agua.2328

CASTRO RIBAS, T.; FORTES NETO, P. Disposição no solo de efluentes de esgoto tratado visando à redução de coliformes termotolerantes. **Revista Ambiente & Água**, v. 3, n. 3, p. 81-94, 2008. https://dx.doi.org/10.4136/ambi-agua.63

CAPODAGLIO, A. G., HLAVÍNEK, P., RABONI, M. Physico-chemical technologies for nitrogen removal from wastewaters: a review. **Revista Ambiente & Água**, p. 481-498, 2015. https://dx.doi.org/10.4136/ambi-agua.1618

CHIAVOLA, A.; TEDESCO, P.; BONI, M. R. Fate of selected drugs in the wastewater treatment plants (WWTPs) for domestic sewage. **Environmental Science and Pollution Research**, p. 1113-1123, 2019. https://dx.doi.org/10.1007/s11356-017-9313-x

COLLINS, H. F. **Effects of initial mixing and Residence Time Distribution on the efficiency of the wastewater chlorination process**. *In:* THE CALIFORNIA STATE DEPARTMENT OF HEALTH ANNUAL SYMPOSIUM, 1970. **Papers[…]** Berkeley; Los Angeles, 1970.

COLLINS, H. F.; SELLECK, R. E. **Process kinetics of wastewater Chlorination**. SERL Report 72-5 Sanitary Engineering Research Laboratory. Berkeley: University of California, 1972.

COPELLI, S.; RABONI, M.; URBINI, G. Water Pollution: Biological Oxidation and Natural Control Techniques. **Reference Module in Chemistry, Molecular Sciences and Chemical Engineering**, p. 1-28, 2015. https://dx.doi.org/10.1016/B978-0-12-409547-2.11419-2

DE ALMEIDA SOARES OLIVEIRA, A.; GASPAR BASTOS, R.; FONSECA SOUZA, C. Adaptation of domestic effluent for agricultural reuse by biological, physical treatment and disinfection by ultraviolet radiation. **Revista Ambiente & Água**, v. 14, n. 2, 2019. https://dx.doi.org/10.4136/ambi-agua.2292

DEMIR, F. Development and validation of a simulation model to determine the reaction rate constant of chlorine disinfection process at a wastewater treatment plant. **Desalination and Water Treatment**, v. 57, n. 19, 2016. https://doi.org/10.1080/19443994.2015.1023850

DE OLIVEIRA PEREIRA, L. C.; ROSSO, T.; CABONELLI CAMPOS, J.; GIORDANO, G. Fenton’s reagent application in the domestic sewers disinfection. **Revista Ambiente & Água**, v. 6, n. 1, p. 65-76, 2011. https://dx.doi.org/10.4136/ambi-agua.174

IRSA (U.S.); APAT. **Analytical methods for water-Report 29/2003**. Rome, 2003.

LUCIANO, A.; VIOTTI, P.; MANCINI, G.; TORRETTA, V. An integrated wastewater treatment system using a BAS reactor with biomass attached to tubular supports. **Journal of Environmental Management**, p. 51-60, 2012. https://dx.doi.org/10.1016/j.jenvman.2012.08.034

RABONI, M.; GAVASCI, R.; VIOTTI, P. Influence of denitrification reactor retention time distribution (RTD) on dissolved oxygen control and nitrogen removal efficiency. **Water Science & Technology**, v. 72, p. 45–51, 2015. https://dx.doi.org/10.2166/wst.2015.188

RABONI, M.; GAVASCI, R.; TORRETTA, V. Assessment of the Fate of Escherichia coli in Different Stages of Wastewater Treatment Plants. **Water, Air, & Soil Pollution**, p. 227-455, 2016. https://dx.doi.org/10.1007/s11270-016-3157-8

RABONI, M.; TORRETTA, V. Validation of a new model for the sizing of denitrification reactors, by testing full-scale plants. **Environmental Technology**, v. 38, p. 1376-1382, 2017. https://doi.org/10.1080/09593330.2016.1228700

TCHOBANOGLOUS, G.; BURTON, F. L.; STENSEL, H. D. **Wastewater Engineering**: Treatment and Reuse. New York: McGraw-Hill, 2003.

TORRETTA, V.; RAGAZZI, M.; TRULLI, E.; DE FEO, G.; URBINI, G.; RABONI, M.; RADA, E.C. Assessment of biological kinetics in a conventional municipal WWTP by means of the oxygen uptake rate method. **Sustainability**, v. 6, p. 1833–1847, 2014. https://dx.doi.org/10.3390/su6041833

TORRETTA, V.; URBINI, G.; RABONI, M.; COPELLI, S.; VIOTTI, P.; LUCIANO, A.; MANCINI, G. Effect of Powdered Activated Carbon to Reduce Fouling in Membrane Bioreactors: A Sustainable Solution. Case Study. **Sustainability**, v. 5, n. 4, p. 1501-1509, 2013. https://doi.org/10.3390/su5041501

USEPA. **Waste Water Treatment Manuals Primary, Secondary And Tertiary Treatment**. Washington, 1997.

USEPA. **Nutrient Control Design Manual**. EPA/600/R-10/100. Washington, 2010.

VERMA, K.; GUPTA, K. D.; GUPTA, A. B. A review on sewage disinfection and need of improvement. **Desalination and Water Treatment,** v. 56, n. 11, p. 2867-28, 2015. https://doi.org/10.1080/19443994.2014.967307

VIOTTI, P.; LUCIANO, A.; MANCINI, G.; TORRETTA, V. A wastewater treatment using a biofilm airlift suspension reactor with biomass attached to supports: A numerical model. **International Journal of Environmental Science and Technology**, p. 571-588, 2014. https://dx.doi.org/10.1007/s13762-013-0256-6

VIOTTI, P.; COLLIVIGNARELLI, M. C.; MARTORELLI, E.; RABONI, M. Oxygen control and improved denitrification efficiency by dosing ferrous ions in the anoxic reactor. **Desalination and Water Treatment**, v. 57, n. 39, 2016. https://dx.doi.org/10.1080/19443994.2015.1089200

WHITE, G. C. **Handbook of Chlorination and Alternatives Disinfectants**. 4th ed. New Yoirk: Wiley & Sons, 1999.

WHITE, G. C. **White's Handbook of Chlorination and Alternative Disinfectants**. 5th ed. New York: John Wiley & Sons, 2010.