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Contemporary Scientific and Technological Aspects towards an Entrepreneurial Approach

Optimizing the Performance of a Simulated Wastewater Treatment Plant by the Relaxation Method

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Abstract: Nowadays, wastewater treatment plants with activated sludge are used to improve the quality of the effluent to be discharged into a body of water. To increase the performance of these stations, different control strategies are implemented and tested. Optimizing a control strategy is a complex activity that involves performing several tests. This paper presents the results obtained in the process of optimizing a control strategy using the method of relaxation. Therefore, the regulation loops of ammonium and nitrate were considered and their optimal references were determined. The simulations were performed with the Benchmark Simulation No.2 (BSM2) model. The data obtained were compared to the results obtained by simulation with the reference strategy of the model.

Keywords: wastewater, mathematical model, simulation, wastewater treatment

1. Introduction

Freshwater quality plays a significant role in maintaining the natural balance present in aquatic ecosystems. This balance is often affected by anthropogenic activities such as pollution. The discharge of wastewater into surface-water bodies can have devastating consequences for different ecosystems even at a great distance from the source of pollution High nitrogen concentrations in wastewater are responsible for the formation of the eutrophication phenomena (Chen *et al.*, 2002). Degradation of freshwater quality also affects human health. Consumption of biologically or chemically contaminated water increases the risk of disease (Gupta & Gupta, 2021; Lofrano & Brown, 2010). Many organic and inorganic compounds found in wastewater are known for their effects on human health: carcinogenicity, mutagenicity, teratogenicity, or high toxicity (Nagwekar, 2014).

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Over time, scientists have realized that water is a vital resource, and maintaining its quality must be a priority. The discovery of the wastewater treatment process with activated sludge by Ardern, E. and Lockett W.T., in 1914 was a solution for this problem.

Nowadays, wastewater treatment plants with activated sludge are used to collect and treat wastewater from various sources (rainwater, industry, domestic use). After this process, the treated water gets discharged into a body of surface water, and the cycle repeats.

The performance of these stations varies depending on the technological endowments they have and how much they are optimized. The operation of these wastewater treatment plants is not without risks, starting from unforeseen weather conditions, to malfunctions and power outages. To operate a treatment plant involves certain costs (electricity consumed, chemicals added in different processes, removal of excess sludge, etc.) (Sonune and Ghate, 2004). Increasing the performance and reducing the operating cost of a wastewater treatment plant is difficult. To obtain the before-mentioned results it is needed to test and optimize different control strategies using simulation models. Testing such control strategies on pilot stations is not recommended due to the risks of polluting aquatic ecosystems. Mathematical models were made that can successfully simulate all the processes that take place in wastewater treatment plants. One model that is well known in this field is BSM2 (Benchmark Simulation Model No.2) (Alex *et al.*, 2018). The continuous development of BSM2 is performed by the IWA Task Group on Benchmarking of Control Strategies for WWTPs (Nopens *et al.*, 2010).

In this study, we propose to utilize the BSM2 model to perform an optimization of a standard virtual wastewater treatment plant using a direct approach by applying modifications to the values for nitrite and ammonia control variables.

2. Materials and Methods

In this paper, the BSM2 model presented in Figure 1 was used to perform the simulations. The model can simulate the wastewater treatment stage and the sludge processing and removal stage. The purpose of BSM2 is to provide an efficient tool to evaluate the performance of proposed control strategies (Jeppsson *et al.*, 2007).

The wastewater treatment stage consists of a primary clarifier, a bioreactor, and a secondary clarifier with 10 levels. The bioreactor is the most important since is the place where the specific nitrification and denitrification processes take place. It consists of 5 compartments, where compartments 1 and 2 are in an anoxic regime, and, compartments 3, 4, and 5 are in aerobic regime.

The sludge processing and removal stage consists of a thickener, an anaerobic digester, and a dewatering unit.

The BSM2 model works using a file or variable that describes a dynamic influent and runs for 609 days. The dynamic influent, representing the water inflows in the wastewater treatment plant, simulates different meteorological conditions for dry and wet weather. The variaţion of the flow rate can show the effect of human activity, and therefore a maximum is recorded during the day and minima during night time. The period between 245 and 609 days of the simulation is reserved to evaluate the overall plant performance.

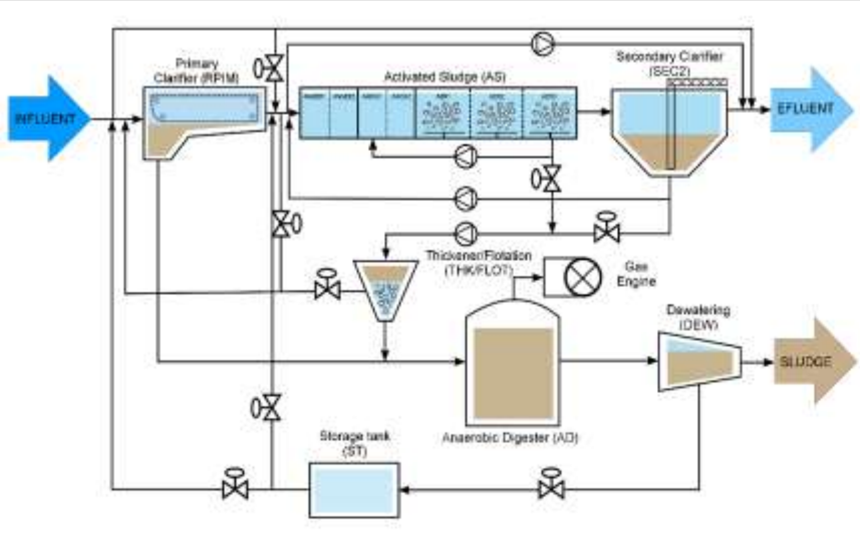

Figure 1. Benchmark Model No.2 Layout (Alex et al., 2018)

În order to evaluate the performance of BSM2 simulations it is necessary to use a mathematical equation that describes the EQI (Effluent Quality Index) and OCI (Overall Cost Index). The EQI was used in such a simulation model by (Alex *et al.*, 2018), and is presented below:

Equation 1 Formula for Effluent Quality Index

$$EQI = \frac{1}{t_{\text{obs}} \cdot 1000} = \int_{t=245\,zile}^{t=609\,zile} \begin{pmatrix} B_{\text{TSS}} \cdot TSS_e(t) + B_{\text{COD}} \cdot COD_{\text{e}}(t) + B_{\text{NKj}} \cdot S_{\text{NKj,e}}(t) \\ +B_{\text{NO}} \cdot S_{\text{NO,e}}(t) + B_{\text{BOD5}} \cdot BOD_{\text{e}}(t) \end{pmatrix} Q_e\,(t) \cdot dt$$

where: *TSS* – total suspended solids, *COD* – chemical oxygen demand, *NKj* - Kjeldahl nitrogen concentration, *NO* – nitrite and nitrate concentration, BOD_5 – biochemical oxygen demand.

Also, the same simulation benchmark used by (Alex *et al.*, 2018) presents the OCI as it follows:

Equation 2 Formula for Overall Cost Index

$$\mathbf{OCI = AE + PE + 3 \cdot SP + 3 \cdot EC + ME - 6 \cdot MET_{prod} + HE_{net}}$$

where: *AE* – aeration energy, *PE* – pumping energy, *SP* – sludge production, *EC* – external carbon consumption, ME – mixing energy, MET_{prod} – methane production, HE_{net} – heating energy.

The standard settings of the BSM2 includes at first run the concentration limits for the effluent compounds considered to be: $N_{tot} < 18$ g N/m^3, $COD_{tot} < 100$ g COD/m^3, $S_{NH} < 4$ g N/m^3, TSS < 30 g SS/m^3, $BOD_5 < 10$ g BOD/m^3.

In this study, it was performed a first control strategy (A1) using BSM2 to test its performance during the simulations. Strategy A1 presents 2 levels of control. The first level is defined to control the NH^+_4 (ammonium) concentrations in the second compartment of the bioreactor, with C (carbon) addition. The default reference value for the control variable $S_{NH,val}$ was considered to be 1 g N/m^3, The second level of control is for controlling the (nitrate) concentrations in compartment 5 of the bioreactor by oxygen insulation. The default reference value for the control variable $S_{NO2,val}$ was considered to be 1 g N/m^3. PI-type controllers have been considered for the simulations.

To compare the results an optimization criterion was defined as it was used by (Luca *et al.*, 2017):

Equation 3 Formula for the optimization criterion

$$\mathbf{O_p} = \boldsymbol{\alpha}\left(\frac{\overline{\mathbf{EQI}}}{\mathbf{3}} + \frac{\overline{\mathbf{TD_{N_{tot}}}}}{\mathbf{3}} + \frac{\overline{\mathbf{TD_{S_{NH,e}}}}}{\mathbf{3}}\right) + (\mathbf{1} - \boldsymbol{\alpha})\overline{\mathbf{OCI}}$$

where: $\overline{EQI}$ and $\overline{OCI}$ represent the scaled values of the plant evaluation indexes, $\overline{TD_{N_{tot}}}$ and $\overline{TD_{S_{NH,e}}}$ represent the scaled values for N_{tot} and $S_{NH,e}$, α is equal to 0.5 and represents the importance of operational cost and water quality.

The relaxation method was used to optimize strategy A1. This optimization method is summarized in 5 steps:

1. 4 values around the reference values of both control variables were considered (the range can be chosen arbitrary);
2. Use all the values considered, including the reference value, in simulations;
3. Calculate the optimization criterion O_p for both control variables;
4. Polynomial interpolation of the data obtained for both control variables;
5. Determine the minimum point from the polynomial interpolation.

3. Results and Discussions

Strategy A1, described above, was considered during the simulations with the BSM2 model. A total of 10 simulations were performed to determine the optimal values for $S_{NO2,val}$ and $S_{NH,val}$. The average duration of each simulation of the entire wastewater plant using BSM2 was about 2 hours using an average performance computer.

The data obtained for $S_{NO2,val}$ indicates that the first three simulations were not close to identifying an optimal value. Figure 2 shows that the optimal value for $S_{NO2,val}$ was identified between simulations 4 and 5, indicating 1.354 g N/m^3.

For $S_{NH,val}$, the last three simulations got high values compared to the second simulation where the minimum point was determined. The optimal value determined for $S_{NH,val}$ is presented in Figure 3, indicating a value of 0.744 g N/m^3.

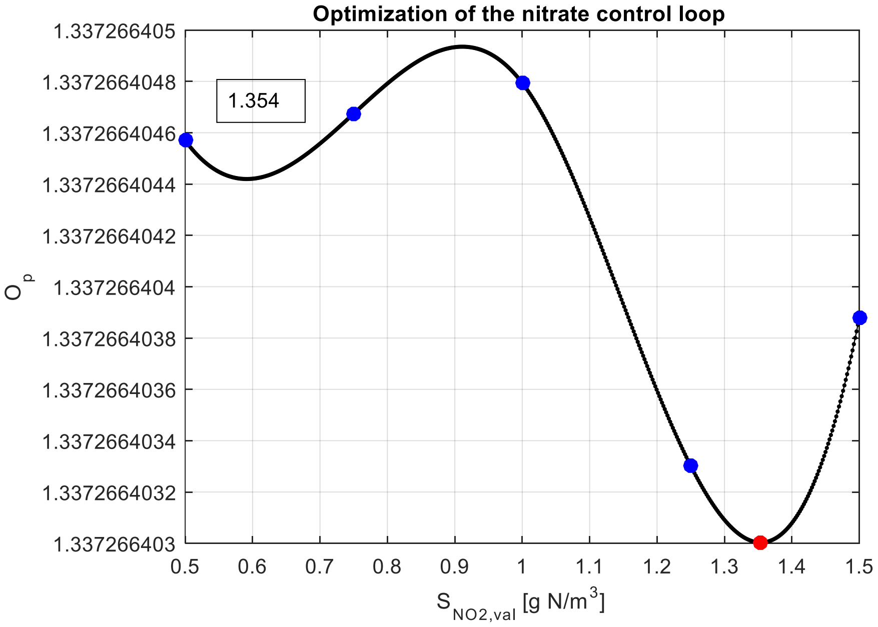

Figure 2. Determination of the Minimum Point from the Polynomial Interpolation for $S_{NO2,val}$ Control Variable

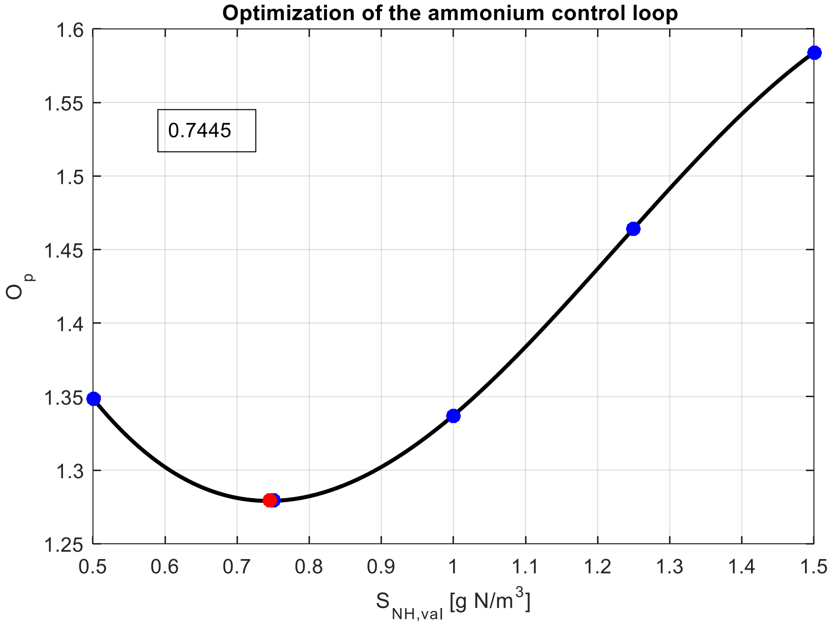

Figure 3. Determination of the Minimum Point from the Polynomial Interpolation for $S_{NH,val}$ Control Variable

4. Conclusions

This paper presents the process of optimizing a control strategy through the relaxation method using random values centered around the standard value of the model for ammonia and nitrite. The results of the study show that this relaxation method is an adaptive one and can be used for different scenarios involving multiple control strategies for various input variables that are used to run the model.

The results obtained imply that this method can help in determining the optimal value for multiple control variables and also to find the lowest values for EQI and OCI which describe a good wastewater plant optimization. The results of such simulation can be used in real wastewater plants to reduce costs and the quality of the effluent.

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