International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 09 - Issue 01 || January 2023 || PP. 01-04

Operational challenges in wastewater treatment - possibilities for improving the operation

Tamas Papp
National University of Public Service, Faculty of Water Science
Bajcsy-Zsilinszky Str. 12-14, HU-6500 Baja, Hungary

Abstract: This research is focused on the use of process control in wastewater treatment systems, with a specific emphasis on aeration control, recirculation stream control, and chemical addition control. The paper covered mathematical background of process control, including the use of differential equations, linear and nonlinear systems, feedback control, and PID control. It also provided information on how to adjust process control by tuning the K parameters, how to optimize the performance of aeration, recirculation stream and chemical addition control by using advanced control strategies such as model predictive control, adaptive control, or optimal control.

Keywords: activated sludge system, operation, process control, wastewater treatment

I. Introduction

Wastewater treatment is a complex process aiming various tasks nowadays, as to effectively remove emerging contaminants, such as microplastics [1-2] and pharmaceuticals [3], treat and reuse wastewater for irrigation and other non-potable uses, to improve the energy efficiency of wastewater treatment processes [4], to integrate wastewater treatment with other forms of resource recovery [5], such as energy generation and nutrient recovery. Furthermore, another series of key questions are how to adapt wastewater treatment processes to address the impacts of climate change due to the increased frequency of extreme weather events [6]. Overall, the operators shall improve the efficiency and cost-effectiveness of biological treatment processes, such as activated sludge or attached growth processes.

Common operational tasks are the following [7]:

1. Screening: Removing large debris, from the wastewater before it enters the treatment process and reducing the size of any remaining debris, such as food scraps, therefore it can be more easily treated.
2. Mechanical treatment: Removing suspended solids and settleable materials, such as grease and oil, from the wastewater through sedimentation or flotation.
3. Secondary treatment: Removing dissolved and colloidal materials, such as bacteria and other microorganisms, from the wastewater through biological processes, such as activated sludge or trickling filters.
4. Tertiary treatment: Removing remaining pollutants, such as nutrients and dissolved chemicals, from the wastewater through advanced treatment processes, such as filtration, disinfection, and reverse osmosis.
5. Sludge treatment and disposal: Treating and disposing of the residual solids produced during the treatment process, such as through anaerobic digestion or land application.
6. Monitoring and reporting: Continuously monitoring the performance of the treatment system and reporting the results to regulatory agencies.
7. Maintenance and repair: Regularly inspecting, maintaining, and repairing equipment and facilities to ensure proper performance and compliance with regulations.

There are many possibilities for improving the operation of wastewater treatment systems. Upgrading or retrofitting existing equipment: Improving the performance of existing equipment by replacing outdated components or adding new technologies, such as membrane bioreactors or advanced oxidation processes. Using advanced control systems, such as SCADA or artificial intelligence, to optimize the performance of the treatment process and reduce energy consumption. Recovering valuable resources, such as energy, nutrients, and water, from the wastewater treatment process, to reduce costs and environmental impact. Reducing energy consumption by using renewable energy sources, such as solar or biogas, and implementing energy-efficient practices, such as combined heat and power [8-9].

Using advanced analytical tools, such as online monitoring, real-time control, and advanced process modeling, to optimize process performance and improve decision-making. Incorporating green infrastructure, such as rain gardens or constructed wetlands, to reduce the volume of wastewater entering the treatment system. Using anaerobic digestion to treat residual solids from the treatment process and generate biogas energy [10].

Incorporating circular economy approach in the design, operation and maintenance of wastewater treatment systems to reduce costs, environmental impacts, and increase resource recovery [11]. From the many concepts in this paper our aim to highlight several aspects of process optimisation.

II. Materials And Methods

There are several adjustments that can be made in process control to improve the performance of a wastewater treatment system:

i) Continuously monitoring key process parameters, such as pH, temperature, and dissolved oxygen, and using this data to make adjustments to the treatment process in real-time.
ii) Advanced process modeling: Using advanced process modeling tools, such as neural networks or fuzzy logic, to optimize the performance of the treatment process and predict future performance.
iii) Adaptive control: Using adaptive control strategies, such as model predictive control or self-optimizing control, to adjust the treatment process in response to changes in influent water quality or flow.
iv) Automatic process control: Using automatic process control systems, such as SCADA or PLC, to control the treatment process and optimize performance based on real-time data.
v) Automated process adjustments: Automating process adjustments, such as aeration or chemical dosing, to improve treatment efficiency and reduce operator error.
vi) Real-time control: Implementing real-time control systems to respond to changes in influent water quality or flow in a timely manner.
vii) Optimizing setpoints: Optimizing setpoints for process parameters, such as pH, dissolved oxygen, and sludge retention time, to improve treatment efficiency and reduce costs.
viii) Implementing advanced analytical tools: Using advanced analytical tools, such as online monitoring, real-time control, and advanced process modeling, to optimize process performance and improve decision-making.
ix) Implementing advanced control strategies: Implementing advanced control strategies, such as model predictive control, adaptive control, and self-optimizing control, to improve the performance of the treatment process.

The mathematical background of process control in wastewater treatment systems typically involves the use of mathematical models and control algorithms to optimize the performance of the treatment process.

PID control is a widely used control algorithm that is based on the proportional, integral, and derivative (PID) control actions. The mathematical foundations of PID control are based on the concept of feedback control, where the control input (such as chemical dosing or aeration) is adjusted based on the difference between the desired output (such as pH or dissolved oxygen) and the current output.

The proportional action in PID control is based on the principle of proportionality, where the control input is proportional to the error (the difference between the desired output and the current output). This action is used to bring the current output closer to the desired output.

The integral action in PID control is based on the principle of integration, where the accumulated error over time is used to adjust the control input. This action is used to eliminate the steady-state error, which is the difference between the desired output and the current output when the system has reached equilibrium.

The derivative action in PID control is based on the principle of differentiation, where the rate of change of the error is used to adjust the control input. This action is used to anticipate the future behavior of the system and prevent overshoots and oscillations in the output [12].

The overall control input is obtained by combining the effect of all three actions :

$$u(t) = Kp * e(t) + Ki * \int e(t)\, dt + Kd * de(t)/dt$$

Where :

u(t) is the control input.

e(t) is the error (the difference between the desired output and the current output).

Kp, Ki and Kd are the proportional, integral and derivative gain respectively.

The PID controller can be adjusted by tuning the gains Kp, Ki and Kd. This tuning process is typically done using techniques such as the Ziegler-Nichols method, the Cohen-Coon method, and the Internal Model Control (IMC) method.

III. Optimisation strategies recomendations

Aeration control

The K parameters for aeration control in a wastewater treatment system are typically the proportional, integral, and derivative gain values used in a PID control algorithm. These parameters are used to adjust the aeration rate in response to changes in the process conditions, such as changes in dissolved oxygen (DO) or pH. The typical values for PID tuning for aeration in a wastewater treatment system can vary widely depending on the specific characteristics of the aeration system and the treatment process [13]. However, some general guidelines for the proportional, integral, and derivative gain values can be:

Proportional gain (Kp): Typically in the range of 0.1 to 2, with a value around 0.5 being a good starting point.

Integral gain (Ki): Typically in the range of 0.01 to 0.1, with a value around 0.05 being a good starting point

Derivative gain (Kd): Typically in the range of 0.1 to 1, with a value around 0.5 being a good starting point. [14]

Recirculation stream control

Recirculation stream control in a wastewater treatment system involves adjusting the flow rate of a recirculation stream in order to optimize the performance of the treatment process. The recirculation stream is typically a portion of the treated wastewater that is returned to an earlier stage in the treatment process in order to improve the overall efficiency of the system [15].

The control of recirculation stream is typically based on a feedback control system, where the flow rate of the recirculation stream is adjusted based on the difference between the desired output (such as dissolved oxygen or pH) and the current output. The control input (the flow rate of the recirculation stream) is adjusted using a control algorithm, such as a PID controller, to bring the current output closer to the desired output.

The process control for recirculation stream is usually done by monitoring the dissolved oxygen (DO) levels in the influent and effluent stream, the pH and the mixed liquor suspended solids (MLSS) levels. The control algorithm can use the following variables to adjust the recirculation flow rate:

The influent flow rate: The control algorithm can be set to maintain a certain ratio of recirculation flow rate to influent flow rate.

The pH levels: The control algorithm can be set to maintain a certain pH level in the effluent stream.

The mixed liquor suspended solids (MLSS) levels: The control algorithm can be set to maintain a certain MLSS level in the mixed liquor.

Tipical values are: MLSS=3-6 g/L, QRAS=0.8*Q, DO=2 mg/L.

Chemical addition control

Chemical addition control in a wastewater treatment system is the process of adjusting the flow rate or concentration of chemicals added to the treatment process in order to optimize the performance of the treatment process. The chemicals are typically added to the treatment process to adjust pH, remove pollutants, or disinfect the water [16].

Chemical addition control is typically based on a feedback control system, where the flow rate or concentration of chemicals is adjusted based on the difference between the desired output (such as pH or dissolved oxygen) and the current output. The control input (the flow rate or concentration of chemicals) is adjusted using a control algorithm, such as a PID controller, to bring the current output closer to the desired output. The process control for chemical addition can be done by monitoring the pH, dissolved oxygen (DO) levels, and other parameters, such as turbidity, conductivity, and chemical oxygen demand (COD).

IV. Conclusion

Process control is a crucial aspect of wastewater treatment systems, as it allows for the optimization of treatment efficiency and the reduction of energy consumption and costs. Aeration control, recirculation stream control, and chemical addition control are three key areas where process control can be applied. PID control is a widely used control algorithm, but other advanced control strategies such as model predictive control, adaptive control, and optimal control can also be used. The optimal values of the K parameters are system-specific and depend on the characteristics of the aeration system, the treatment process, and the desired performance. Monitoring and adjusting the parameters over time is important to ensure optimal performance of the system.

References

[1]. Sun, J., Dai, X., Wang, Q., van Loosdrecht, M. C., & Ni, B. J. (2019). Microplastics in wastewater treatment plants: Detection, occurrence and removal. *Water research*, *152*, 21-37.

[2]. Ziajahromi, S., Neale, P. A., Rintoul, L., & Leusch, F. D. (2017). Wastewater treatment plants as a pathway for microplastics: development of a new approach to sample wastewater-based microplastics. *Water research*, *112*, 93-99.

[3]. Guo, Y., Qi, P. S., & Liu, Y. Z. (2017, May). A review on advanced treatment of pharmaceutical wastewater. In *IOP Conference Series: Earth and Environmental Science* (Vol. 63, No. 1, p. 012025). IOP Publishing.

[4]. Karches, T. (2012). Evaluation of mixing efficiency in coagulation-flocculation process in wastewater treatment. *Journal of Environmental Science and Engineering. A*, *1*(7A), 898.

[5]. Solon, K., Volcke, E. I., Spérandio, M., & Van Loosdrecht, M. C. (2019). Resource recovery and wastewater treatment modelling. *Environmental Science: Water Research & Technology*, *5*(4), 631-642.

[6]. Vo, P. T., Ngo, H. H., Guo, W., Zhou, J. L., Nguyen, P. D., Listowski, A., & Wang, X. C. (2014). A mini-review on the impacts of climate change on wastewater reclamation and reuse. *Science of the Total Environment*, *494*, 9-17.

[7]. Spellman, F. R. (2008). *Handbook of water and wastewater treatment plant operations*. CRC press.

[8]. Wang, Y., Li, J., Wang, S., Yang, J., Qi, C., Guo, H., ... & Zhang, H. (2020). Operational optimization of wastewater reuse integrated energy system. *Energy*, *200*, 117309.

[9]. Bába, B., & Karches, T. (2021). Operation improvement of sequencing FED-batch wastewater treatment. *Pollack Periodica*, *16*(2), 61-66.

[10]. Lettinga, G. (1995). Anaerobic digestion and wastewater treatment systems. *Antonie van leeuwenhoek*, *67*(1), 3-28.

[11]. [Guerra-Rodríguez, S., Oulego, P., Rodríguez, E., Singh, D. N., & Rodríguez-Chueca, J. (2020). Towards the implementation of circular economy in the wastewater sector: Challenges and opportunities. *Water*, *12*(5), 1431.

[12]. Silva, G. J., Datta, A., & Bhattacharyya, S. P. (2005). *PID controllers for time-delay systems* (Vol. 43). Boston: Birkhäuser.

[13]. Karches, T. (2022). Fine-Tuning the Aeration Control for Energy-Efficient Operation in a Small Sewage Treatment Plant by Applying Biokinetic Modeling. *Energies*, *15*(17), 6113.

[14]. Åmand, L., Olsson, G., & Carlsson, B. (2013). Aeration control–a review. *Water Science and Technology*, *67*(11), 2374-2398.

[15]. Karches, T. (2018). Effect of internal recirculation on reactor models in wastewater treatment. *WIT Transactions on Ecology and the Environment*, *228*, 145-153.

[16]. Clark, T., & Stephenson, T. (1998). Effects of chemical addition on aerobic biological treatment of municipal wastewater. *Environmental technology*, *19*(6), 579-590.