DISINFECTION BY UV RADIATION FOR WASTEWATER REUSE: OPTIMISATION AND CONTROL

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ABSTRACT
With the raised awareness of toxic disinfection by-products (DBPs) released when chlorine-based compounds are used to disinfect water, the interest in finding safe disinfection methods has increased, especially when talking about wastewater reuse. UV radiation is a reliable and safe disinfection method, but the quality of wastewater greatly affects its performance and monitoring systems provided by manufacturers are often not robust enough. Another reliable alternative is represented by peracetic acid (PAA), an emerging disinfectant that has proven to be effective and is not quoted for producing toxic DBPs.
In this paper we explain our work towards creating a model for the optimisation and control of an existing UV disinfection process. This paper presents the first step in the model development; it aims at describing a multi-physical system in which hydrodynamics, UV radiation and chemical reactions are interacting at the same time, by means of advanced modelling techniques based on machine learning (i.e., Artificial Neural Networks). The final model will include the activation of additional PAA dosage when provisionally needed to comply with the target disinfection levels.

KEYWORDS
Water reuse, disinfection, UV, peracetic acid, optimization and control, artificial neural networks

INTRODUCTION
Wastewater treatment processes have become more efficient in past few decades and regulations on effluent discharge have been getting more stringent. Since awareness on water scarcity is growing worldwide, practices like wastewater reuse are more popular nowadays; therefore, the demand of developing and improving safe related technologies is getting higher (Metcalf & Eddy, Inc., 2007). Disinfection is one of the most important processes in wastewater treatment, especially for the reuse of reclaimed wastewater for activities that include human contact or agricultural use. The technology for pathogen inactivation needs to be selected carefully so it does not compromise the safety of the effluent, both in terms of pathogens and toxic disinfection by-products (DBPs) content (Metcalf & Eddy, Inc., 2014). Chlorine-based compounds and ozone are known for being good disinfectants but also for reacting with natural organic matter, anthropogenic contaminants, bromide and iodide contained in treated wastewater, resulting in DBPs that are many times carcinogen and mutagenic (Lee et al., 2015). A safe, proven alternative is UV radiation, as it is highly effective and does not produce any toxic DBP; however, it requires a robust monitoring and control system that is often not fully covered by manufacturers, and its effectiveness decreases depending on the optical properties of the bulk liquid. Another safe disinfectant, which is not greatly affected by suspended solids, is peracetic acid (PAA); although it has

been commonly used in food industry, in the last 20 years it has been increasingly used for wastewater disinfection (Antonelli et al., 2006).

In order to provide a safe disinfection method for reclaimed wastewater to be used for irrigation purposes, we are developing a model for the optimisation and control of a UV disinfection process. This model includes an additional dosage of PAA when provisionally needed to comply with the target disinfection levels. The model will be able to describe a multi-physical system in which hydrodynamics, UV radiation and chemical reactions are interacting at the same time by means of advanced modelling techniques based on machine learning (i.e., Artificial Neural Network, ANN). In this paper, a preliminary step in the development of the model is presented, in which data collected from a full-scale wastewater disinfection unit of a wastewater treatment plant (WWTP) in the city of Milan (Italy) were used as a first application.

MATERIALS AND METHODS

An ANN was developed as a predictive model for providing real-time information to the control system. ANN is a "black-box" model, based on a large database including input and output values. This database is used for model training, in which the functions for relating inputs and outputs are defined via a network of connected units. By these functions the model predicts the output value of the system when new data is entered as input (Dayhoff & DeLeo, 2001).

Since the database that will be used to train the ANN is still under construction, in the view of testing the model concept, some historic data were used. The database was built based on daily monitoring measurements in the disinfection unit of the WWTP selected as case study, during the irrigation periods of 2015 and 2016, meaning from mid-August to mid-September. The database consisted of 167 entries and contained measurements of total suspended solids (TSS) (mg/L), turbidity (NTU), iron content (mg/L), flow rate (m^3/s), UV dose (mJ/cm^2), and total concentration of *E. coli* in the effluent (CFU/100 mL) after UV disinfection. The latter was set as output of the ANN.

The Neural Network toolbox provided in Mathworks Matlab (R2017b) was used for developing the ANN, choosing the Input-Output and curve fitting app. The Levenberg-Marquardt back-propagation algorithm (trainlm) was chosen for the training phase and a total of 16 neurons in one hidden layer were set as the network architecture (Figure 1). The database was split for the back-propagation training method, the testing and the validation of the model in a division of 65%, 20% and 15%, respectively.

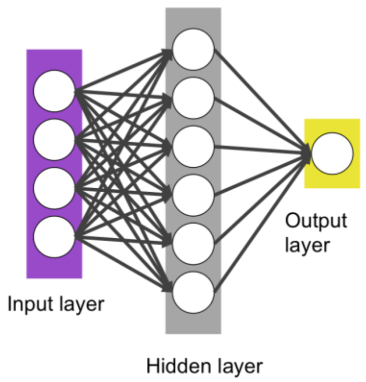

Figure 1. Scheme of an ANN architecture with one hidden layer and 6 neurons in it.

This model is designed to describe the influence of the input factors on the disinfection process giving as result the total *E. coli* concentration once the effluent has been disinfected. It is the first step of the model for process optimization and control, which will also consider extra factors, such as total concentration of *E. coli* before UV disinfection, lamp fouling and random malfunctioning, in order to predict the inactivation efficiency as a function of occurring conditions and to ensure the inactivation effectiveness according to regulatory limits by means of an additional dosage of PAA. As a preliminary step, the main goal of the present paper is to demonstrate the effectiveness of the proposed modeling approach, namely the use of an ANN to predict the total concentration of *E. coli* after UV disinfection as function of the input parameters.

RESULTS AND DISCUSION

The ANN regression on the database did not return excellent results, although the model successfully provided rough estimations of data trend of the total concentration of *E. coli* after UV disinfection. The performance was as follows: Training: R = 0.736, Validation: R = 0.865, Testing: R = 0.815. These results are probably due to the scarce quality of available database, a key aspect for ANN.

Once the on-going data collection campaign is finished, the model will be trained again and higher performance is expected, also due to the possible relevant influence of extra factors taken into account. Moreover, a thorough uncertainty analysis will be carried out.

The resulting ANN model will be set up for working in real-time using information from monitoring probes in combination with a control system. The control system will command the adjustment of the UV dose, increasing it in case the inactivation reference value for reuse (10 CFU/100 ml of *E. coli*) is not reached, or decreasing it in case the concentration of *E. coli* after UV disinfection is much lower than the reference value, in order to optimise the energy consumption. In case that the UV disinfection is operated at maximum potential and the total concentration of *E. coli* in the effluent is still above the reference value, an additional dosage of PAA will be activated to couple with the UV disinfection and to comply with regulations on discharge. A series of batch tests on PAA disinfection are now on progress, to obtain the kinetic parameters to be included in the model for accounting for PAA decay and efficiency in microbial inactivation as a function of effluent physical-chemical characteristics. The functioning of the control system in detailed can bee seen on the flow chart in Figure 2.

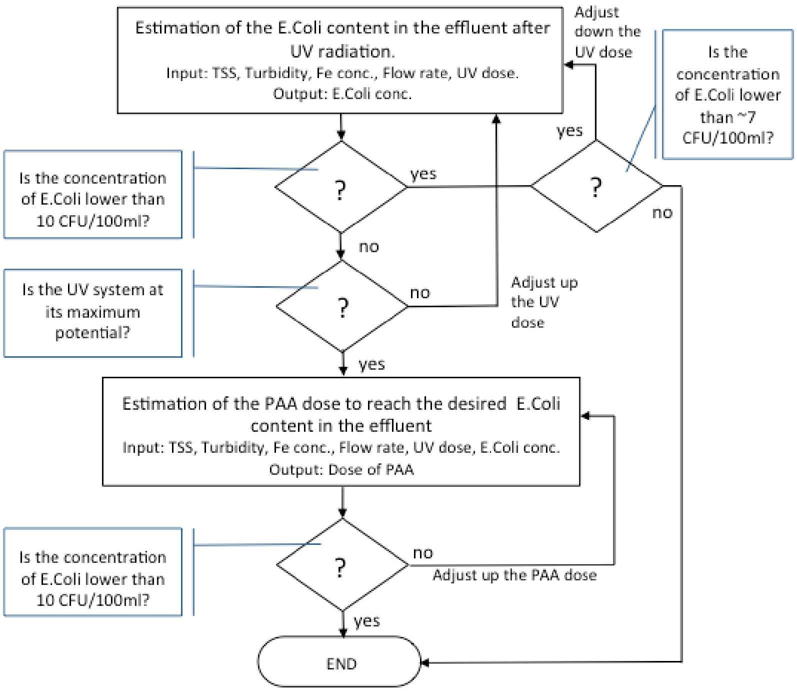

Figure 2. Flow chart of the full model with control system.

The reference *E. coli* concentration after disinfection to lower the UV dose is set at 7, however this value can be changed according to the inactivation required (e.g. adding viruses inactivation, which requires a higher UV dose than *E. coli*).

CONCLUSION

In the paper, a model strategy based on ANN has been introduced and preliminary results are presented, indicating that the system is capable of achieving satisfactory prediction of *E. coli* inactivation based on the input parameters. It is expected that when the database is integrated by means of a dedicated monitoring campaign currently on-going, the system performance will be significantly improved. Such system will be subsequently integrated with a real-time monitoring system for real-time collection of input parameters and with a control system for the optimized operation of the UV disinfection units and an additional PAA dosage unit.

A robust model for safe and reliable wastewater disinfection process is crucial for the current design of the so-called smart cities that are including wastewater reuse in their urban planning. The proposed model can be adapted to fit the characteristics of other full-scale facilities around the world and promote the implementation of wastewater reuse with no risk for public health while reaching more stringent disinfection levels of pathogen inactivation.

The fact that an ANN can be successfully used to study the disinfection process of treated wastewater is a very interesting approach for environmental processes nowadays. Processes that produce large amounts of data could be approached by machine learning modelling tools and promote environmental-friendly models and practices around the world.

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