Conférence Internationale en Automatique & Traitement de Signal (ATS-2017)
Proceedings of Engineering and Technology – PET
Vol.23pp.78-82

# Model Reference Following Control of a UV Water Disinfection System

Khira Ouelhazi[1], Abderrahmen Ben Chaabene[1], Anis Sellami[1], Abdennaceur Hassen[2]

[1] *Laboratory of Industrial Systems Engineering and Renewable Energies (LISIER) (code: LR16ES03), High National School of Engineers of Tunis (ENSIT), 5 Avenue Taha Hussein, Tunisia*

khira.ouelhazi@yahoo.fr

abd.chaabene@yahoo.fr

anis.sellami.@topnet.tn

[2]*Centre of Research and Technologies of Water (CERTE), Laboratory of wastewater Treatment and Valorisation, Borj-Cédria Science and Technology Park, BP 273, 8020 Soliman. Tunis. Tunisia*

abdohas@gmail.com

***Abstract*— The use of ultraviolet irradiation is an interesting technique among the possible alternatives used to disinfect drinking water from harmful microorganisms. The UV disinfection treatment is a highly complex operation where physical, biological and chemical processes are involved. Several parameters can influence the disinfection operation; essentially are water quality characteristics, exposure time and UV intensity. These parameters are variable over time and the output of the system must be adjusted in real time according to the changes of these parameters. Improving the quality of disinfected water requires then an efficient control and better optimization of the disinfection process. A suitable control strategy approach based on the Variable Structure Model Reference Adaptive Control is applied to the disinfection system.**

**Simulations of the proposed control show perfect following between the system to be adjusted and the reference model.**

***Keywords*— UV water disinfection, Model reference following control, Multivariable systems, UV Dose, State space model.**

## I. INTRODUCTION

Some agglomerations are fed by individual water sources because the drinking water distribution network does not cover the entire of the country. Since these waters are not usually treated or disinfected, they could be factors of certain disease transmission. One alternative that has received considerable interest and was widely used in the treatment of drinking water is disinfection with UV radiation [1]–[2]. Generally, most current UV disinfection systems employ tubular germicidal lamps surrounded by a quartz tube submerged in a chamber through which the fluid flows. The UV source of radiation used is usually a low-pressure mercury arc lamp that generates short-wave ultraviolet in the region of 253.7 nm [3], [4]–[5]. Several parameters can influence the rate of inactivation of micro-organisms such as the physico-chemical parameters (pH, temperature etc.…), the UV dose applied, the UV-water contact time, and the number and the type of microorganisms existing in the water [6]. In this context, the UV disinfection unit is considered as a Multi Input Multi Output system and the relation between output and input variables is given by a transfer matrix [7]. This model suitable for simulations, dynamic analysis and optimization is used to establish a control strategy in order to ensure an optimum operating condition.

This control strategy is characterized by the combination of the properties of the adaptive control and the variable structure control. The principle of this control consists in causing the controlled system to follow a reference model whose characteristics are chosen in advance in order to improve the operating performance.

This paper is organized as follows: The first part is devoted to the description of the UV water disinfection system. The theoretical elements of the control action based on model reference following control (MRFC) algorithms are dealt with in the second part. Finally, results and simulations are presented in the third section.

## II. UV WATER DISINFECTION SYSTEM PRESENTATION

### A. Description of the UV disinfection system

The disinfection system as described in [7] consists of a closed cylindrical stainless reactor of annular section, 70 cm length, 6 cm internal diameter and 2l useful volume. It is equipped with a single low pressure mercury discharge lamp placed in the axis of the irradiation room and protected by a clean quartz sleeve used to mechanically protect and seal the lamp as shown in fig. 1. The disinfection system is also equipped, with a motor pump for aspirating contaminated water from the inlet tank, a flow control valve to obtain flow rates ranging from 0.2 to 0.8 L/s and a filter for improving the transmittance of the contaminated water.

### B. The UV disinfection system model

Fig. 2 shows the static model where the disinfection unit is considered as a multivariable system with two inputs and two outputs. The feed flow $Q$ and the UV lamp intensity $I$ were considered as input parameters or manipulated variables. UV dose $D$ and bacterial reduction $A$ were defined as output parameters or set variables. The transmittance $T_r$ of water at the entry was considered as a disruptive input.

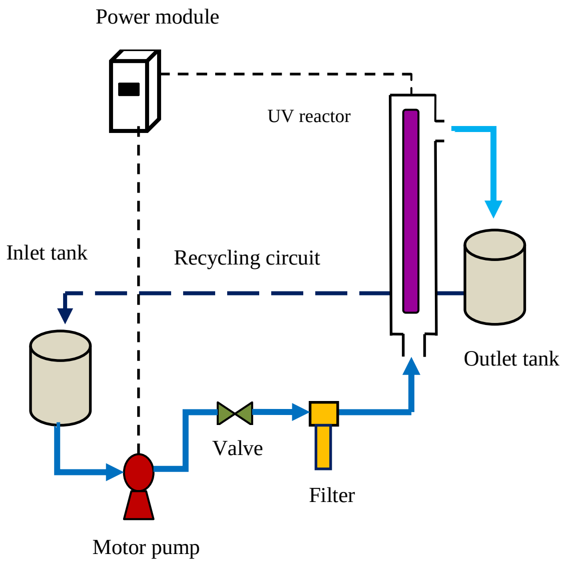


Fig.1 Schematic diagram of the UV disinfection system

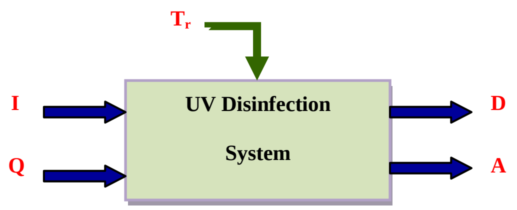


Fig. 2 Static model of the UV disinfection system

### C. *The disinfection system state space model*

The state equations representing the system [7] are:

$$\begin{cases} \dot{X} = AX + BU \\ Y = CX \end{cases} \tag{1}$$

Where

$$X = \begin{bmatrix} D \\ \dot{D} \\ A \\ \dot{A} \end{bmatrix} \quad U = \begin{bmatrix} I \\ Q \end{bmatrix} \quad Y = \begin{bmatrix} D \\ M \end{bmatrix}$$

Matrices A, B and C are defined as follows:

$$A = \begin{pmatrix} 0 & 1 & 0 & 0 \\ -6.02 & -6.77 & 0 & 0 \\ 0 & 0 & -0.56 & 1 \\ 0 & 0 & -0.70 & -1.67 \end{pmatrix}$$

$$B = \begin{pmatrix} 1 & 0 \\ 0 & 98.86 \\ 0 & 1.56 \\ 0.55 & 0 \end{pmatrix}$$

$$C = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

## III. Control Strategy of the UV Disinfection System

### A. *MRFC Algorithm*

Fig. 3 shows the block diagram of the MRFC algorithm as described in [8]. This configuration aims to have a perfect tracking regardless of the parameters variations of the system to be adjusted. The adaptation with the variable structure is performed by switching at the control element. In this structure the error vector and the state vector are both switched. They represent the components of a matrix $\Psi$ that ensures rapid attenuability and reinforces the stability of the system by using a Lyapunov function.

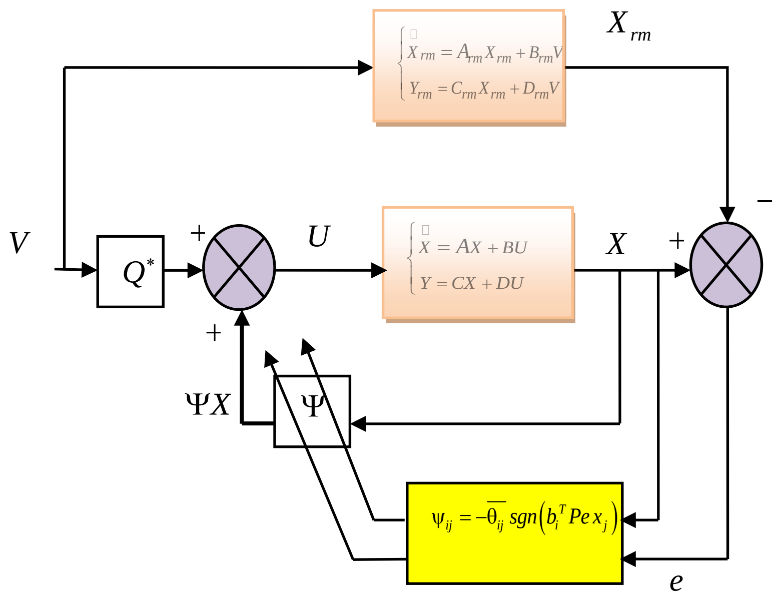


Fig. 3 Model reference following control algorithm block diagram

The state space representation of a Multi Input Multi Output (MIMO) system is:

$$\begin{cases} \dot{X} = AX + BU \\ Y = CX + DU \end{cases} \quad (2)$$

State vector $X$, control vector $U$ are respectively $n$ and $m$ dimensional vectors. Matrices $A$ and $B$ may be variable. Matrix $B$ is partitioned as:

$$B = \left[ b_1 \ b_2 \ \ldots \ b_m \right]$$

The reference model is represented in the state space by:

$$\begin{cases} \dot{X}_{rm} = A_{rm} X_{rm} + B_{rm} V \\ Y_{rm} = C_{rm} X_{rm} \end{cases} \quad (3)$$

Where $A_{rm}$ is an asymptotically stable matrix and $B_{rm}$ is a known matrix.
$X_{rm}$ and $V$ have the same dimension respectively as $X$ and $U$.

The matrices $A_{rm}$ and $B_{rm}$ are defined as follows:

$$A_{rm} = A + B\theta^*$$
$$B_{rm} = B \quad (4)$$

Where $\theta^*$ is an (mxn) dimensional matrix.

The error vector $e$ between the process state space vector and the reference state space vector is:

$$e = X - X_r \quad (5)$$

The purpose is to form the control vector $U$ that prescribes in advance the transient process of the error between the reference model and the plant outputs. Then the control vector $U$ will force the error elements to tend asymptotically to zero at a finite time [8]–[9].

The control vector $U$ is generated introducing control law:

$$U = \psi X + V \quad (6)$$

$\psi$ is the feedback matrix with the dimension (m x n). The elements $\Psi_{ij}$ are switching functions adjusted using a variable structure approach.

The model of the entire system in the error state space equation is obtained as:

$$\dot{e} = A_{rm} e + B(\psi - \theta^*) X \quad (7)$$

To ensure stability, consider a Lyapunov function of the form:

$$\Lambda = e^T P e \quad (8)$$

Where, P is a positive definite and symmetric matrix, consequently we have:

$$A_{rm}{}^T P + P A_{rm} = -Q_0 = -B_{rm}^T B_{rm} \quad (9)$$

Differentiating (8) with respect to time along the trajectory (7) yields:

$$\dot{\Lambda} = -e^T Q_0 e + 2e^T PB[(\psi - \theta^*) X \quad (10)$$

$$\dot{\Lambda} = -e^T Q_0 e + 2\sum_{i=1}^{m} \left\{ b_i^T Pe \sum_{j=1}^{n} \left( \psi_{ij} - \theta_{ij}^* \right) x_j \right\} \quad (11)$$

The switching functions are defined as:

$$\psi_{ij} = -\bar{\theta}_{ij} \ \mathrm{sgn}(b_i^T Pex_j) \quad (12)$$

With: $\bar{\theta}_{ij} > \left| \theta_{ij}^* \right|$

By introducing this expression into (11), we obtain:

$$\dot{\Lambda} = -e^T Q_0 e + 2\sum_{i=1}^{m} \left\{ b_i^T Pe \sum_{j=1}^{n} \left( -\bar{\theta}_{ij} \ \mathrm{sgn}(b_i^T Pex_j) - \theta_{ij}^* \right) x_j \right\} \quad (13)$$

The terms in the summation are always positive, therefore $\dot{\Lambda} < 0$ and regarding (8) it can be concluded that $\|e\|$ decreases at least exponentially.

## IV. Application of The Reference Model

### A. *Calculation and Choice of Parameters*

The rreference model matrices are:

$$A_{rm} = \begin{pmatrix} 0 & 1.1 & 0 & 0 \\ -5.42 & -6.1 & 0 & 0 \\ 0 & 0 & -0.47 & 1.10 \\ 0 & 0 & -0.62 & -1.50 \end{pmatrix}$$

$$B_{rm} = \begin{pmatrix} 1 & 0 \\ 0 & 98.86 \\ 0 & 1.56 \\ 0.55 & 0 \end{pmatrix}$$

$$\theta^* = B^{-1}\left( A_{rm} - A \right) = \begin{pmatrix} -0.0362 & -0.0362 & 0.0141 & 0.0270 \\ 0.3959 & 0.1584 & 0.0566 & 0.0566 \end{pmatrix}$$

$$\bar{\theta} = \begin{pmatrix} 0.04 & 0.04 & 0.02 & 0.03 \\ 0.5 & 0.2 & 0.066 & 0.066 \end{pmatrix}$$

### B. *Results and Simulation*

Results of simulations are shown in the following figures.
Fig. 4a and fig. 4b show respectively the step responses of the UV dose $D$ and the bacterial abatement $A$.
Fig. 5a and fig. 5b show the following error behavior between the reference model and the system outputs.
These results show perfect model following at a finite time. This is also justified by the behavior of the tracking error that

vanishes in a short time.

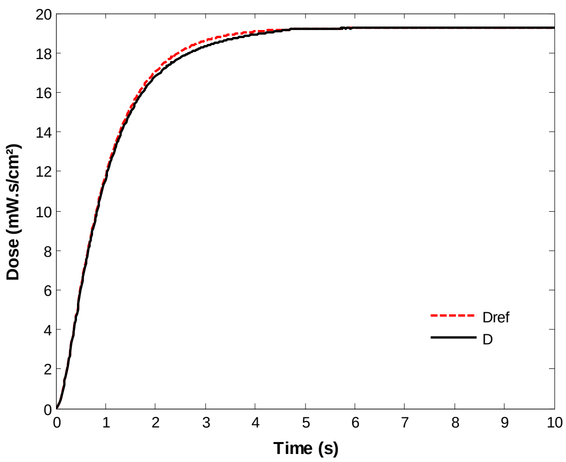


Fig. 4a Step response of the UV dose

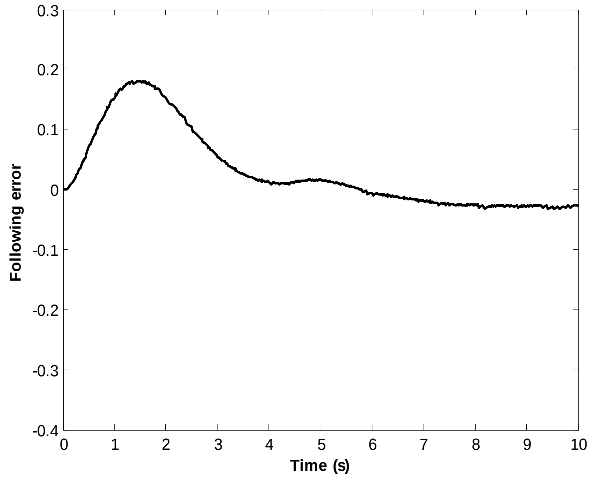


Fig. 5b The bacterial abatement following error behavior

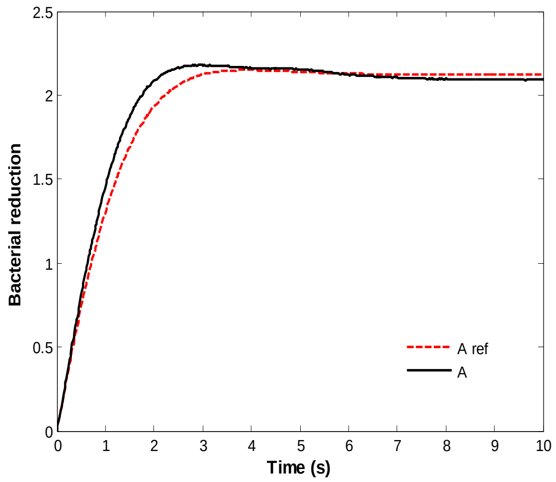


Fig. 4b Step response of the bacterial abatement

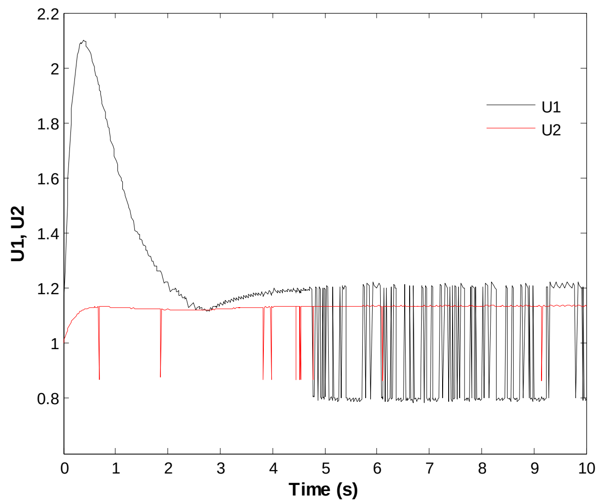


Fig. 6 Control evolution

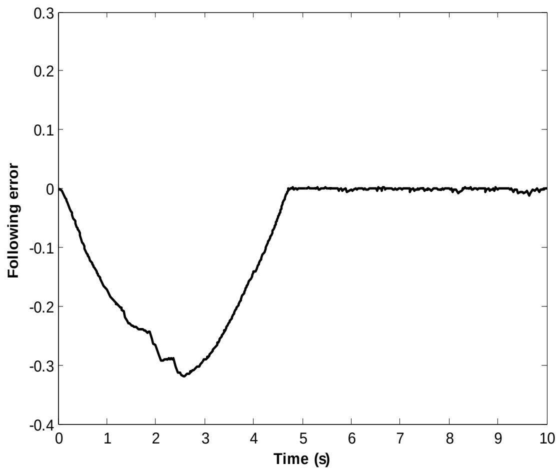


Fig. 5a The UV dose following error behavior

## V. Conclusion

In this paper, a control strategy based on model reference following control was presented. This approach is characterized by its zero output error tracking at a finite time. Results show perfect model following between the system and the model reference and

The combination of the adaptive and the variable structure control improve the performances and the robustness of the proposed system control.

## ACKNOWLEDGMENT

The authors gratefully acknowledge the support rendered by the Ministry of High Education and Scientific Research. We thank all the team of the wastewater pilot plant El Menzeh I for their great and effectively contribution to achieve this work.

## REFERENCES

[1] G. D. Harris, V. D. Adams, D. L. Sorensen, M. S. Curtis, "Ultraviolet inactivation of selected bacteria and viruses with photo reactivation of the bacteria," *Water Res*., vol. 21, pp. 687–692, 1987.

[2] J.J. Vélez-Colmenares, A. Acevedo, E. Nebot, "Effect of recirculation and initial concentration of microorganisms on the disinfection kinetics of *Escherichia coli*," *Desalination*, vol. 280, pp. 20–26, 2011.

[3] K. Chiu, D. A. Lyn, P. Savoye, E. R. Blatchley III, "Integrated UV disinfection model based on particle tracking," *J. Environ. Eng*., vol. 125, pp. 7–16, 1999.

[4] M. Brahmi, H. Abdennaceur, "Ultraviolet radiation for microorganism inactivation in wastewater," *J. Environ. Prot*., vol. 3, pp. 194–202, 2012.

[5] R. G. Qualls, J. D. Johnson, "Modeling and efficiency of ultraviolet disinfection systems," *Water Res*., vol. 19, pp. 1039–1046, 1985.

[6] M. Brahmi, N. H. Belhadi, H. Hamdi, A. Hassen, "Modeling of secondary treated wastewater disinfection by UV irradiation: Effects of suspended solids content," *J. Environ. Sci*., vol. 22, pp. 1218–1224, 2010.

[7] Khira Ouelhazi, Abderrahmen Ben Chaabene, Anis Sellami, Abdennaceur Hassen, "Multivariable Model of an Ultraviolet Water Disinfection System," *Desal. Wat. Treat.* Accepted manuscript, Dec. 2016.

[8] A. B. Chaabene, A. Sellami, "A novel control of a Reverse Osmosis Desalination system powered by photovoltaic generator," in *EEE Xplore*, 2013, p. 1–6, DOI: 10.1109/ICEESA.2013.6578376

[9] K. M. Ardeshir, "A variable structure MRAC for a class of MIMO systems", *International J. of Mechanical Systems Science and Engineering*, vol. 1 (2), pp. 4-79, 2007.


ISSN 2356-5608