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# FUZZY CONTROL OF THE ACTIVATED SLUDGE WASTEWATER TREATMENT PROCESS TREATED AS MULTIVARIABLE PROCESS

**Alina Chiroşcă, George Dumitraşcu, Laurentiu Luca, Sergiu Caraman**

*Department of Automatic Control, “Dunărea de Jos” University of Galaţi*
*Domnească Street No.47, 800008 Galaţi, România*
*E-mail: Alina.Chirosca@ugal.ro*

Abstract: The paper deals with the design of a fuzzy controller of a wastewater treatment process in which the organic substances are removed. The process is complex, nonlinear, time-varying and multivariable, so is necessary to analyze the disturbance rejection and robustness problems. The main contribution of this paper is to give a multivariable fuzzy controller for step disturbance and uncertainty rejection in the wastewater treatment process.

Keywords: fuzzy control, multivariable control, wastewater treatment plant, robustness, disturbance rejection.

## 1. INTRODUCTION

The wastewater treatment is extremely important for humans and other lifeforms. Generally, the wastewater is exposed to different processes which can remove most of the pollutants: organic substances, ammonium, phosphorus and other residuals from the industrial environment and urban or rural communities.

Wastewater treatment processes are very complex, strongly nonlinear and characterized by uncertainties regarding its parameters (Goodman and Englande, 1974). There are many models, in specialized literature, that try to capture as closely as possible the evolution of the wastewater treatment processes with active sludge (Henze, *et al.*, 2000). The modeling of these processes is made globally, considering the nonlinear dynamics, but trying in the same time to simplify the models used in control (Barbu, 2009).

The process control of wastewater treatment is difficult because of low repeatability rate, slow responses and the lack or the high cost of measuring instruments for the state variables of the bioprocesses (biomass concentration, COD concentration etc.). In the literature, to control this process, are used advanced and robust control laws. There are many approaches regarding the control of wastewater treatment processes as main objective: PI and PID-control, nonlinear control, model-based control etc. (Olsson and Newell, 1999). The robust QFT method was also used, but it was applied just in simulation regime (Garcia-Sanz, *et al.*, 2008; Barbu and Caraman, 2007). Artificial intelligence has been also approached to control wastewater treatment processes. Fuzzy controllers and expert systems were used in control application for the processes mentioned before. The fuzzy systems are a particular case of expert systems. A fuzzy system represents a flexible method to treat the model uncertainties. Neural networks were used to approximate the behaviour of the wastewater treatment processes, they being successfully used in model-based control algorithms.

The paper’s objective is to design a multivariable fuzzy controller for the wastewater treatment process. In the considered process, the wastewater is treated to remove organic substances. The paper is structured as follows: the second section presents the wastewater treatment process and its mathematical model, the third section contains the fuzzy controller and an analysis of the rejection of the disturbances and parametric uncertainties and the last is dedicated to the conclusions.

## 2. THE MODEL OF THE WASTEWATER TREATMENT PROCESS

Figure 1 presents the main components of the wastewater treatment process (Katebi, *et al.*, 1999), (Barbu, *et al.*, 2005):

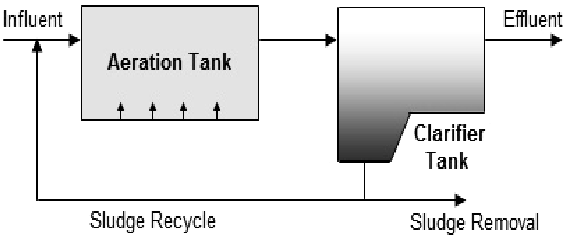

Fig.1. Activated Sludge Process

The *Aeration Tank* is a biological reactor containing a mixture of liquid and suspended solids, where a microorganism’s population (the sludge) is developed aiming to remove the organic substrate from the mixture. The *Clarifier Tank* is a gravity settlement tank where the sludge and the clear effluent are separated. A part of the removed sludge is recycled back to the aeration tank and the other part is removed (Katebi, *et al.*, 1999). The process model has been determined based on mass balance equations. It is given by the following equations (Nejjari, *et al.*, 1996):

$$(1)\quad \frac{dX}{dt} = \mu(t)X(t) - D(t)(1+r)X(t) + rD(t)X_r(t)$$

$$(2)\quad \frac{dS}{dt} = -\frac{\mu(t)}{Y}X(t) - D(t)(1+r)S(t) + D(t)S_{in}$$

$$(3)\quad \begin{aligned} \frac{dDO}{dt} &= -\frac{K_0\mu(t)X(t)}{Y} - D(t)(1+r)DO(t) + \\ &+ \alpha W(DO_{\max} - DO(t)) + D(t)DO_{in} \end{aligned}$$

$$(4)\quad \frac{dX_r}{dt} = D(t)(1+r)X(t) - D(t)(\beta + r)X_r(t)$$

$$(5)\quad \mu(t) = \mu_{\max}\frac{S(t)}{k_s + S(t)}\frac{DO(t)}{K_{DO} + DO(t)}$$

where: $X(t)$ – biomass (the sludge); $S(t)$ – substrate (organic substance concentration); $DO(t)$ – dissolved oxygen concentration; $DO_{max}$ – maximum dissolved oxygen concentration; $X_r(t)$ – recycled sludge; $D(t)$ – dilution rate; $S_{in}$ and $DO_{in}$ – substrate and dissolved oxygen concentrations in the influent; $Y$ – biomass yield factor; $\mu$ – biomass growth rate; $\mu_{max}$ – maximum specific growth rate; $k_s$ and $K_{DO}$ – saturation constants; $\alpha$ – oxygen transfer rate; $W$ – aeration rate; $K_0$ – model constant; $r$ and $\beta$ – ratio of recycled and waste flow to the influent.

The model coefficients are set to the following values: $Y$=0.65, $\beta$=0.2, $\alpha$=0.018, $K_0$=0.5, $K_{DO}$=0.5, $\mu_{max}$=0.15mg/l, $k_s$=100mg/l, $DO_{max}$=10mg/l, $r$=0.6. The initial conditions considered in simulation are: $X(0)=200mg/l$, $S(0)=88mg/l$, $DO(0)=5mg/l$, $X_r(0)=320mg/l$, $DO_{in}=0.5mg/l$ and $S_{in}=200mg/l$.

The wastewater treatment process considered in the paper is a multivariable process, since it can be controlled through the following two control variables: the dilution rate and the aeration rate. The output variables are dissolved oxygen concentration and substrate concentration from the effluent. That means that, when one of the inputs is changing, all of the outputs will be affected.

Figure 2 presents the systemic scheme of the wastewater treatment process:

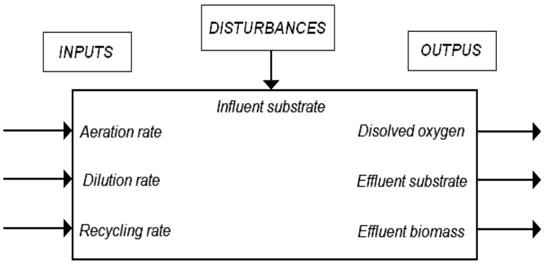

Fig.2. The systemic scheme of the wastewater treatment process

The simulation results concerning the free dynamics of the model are presented in Figure 3.

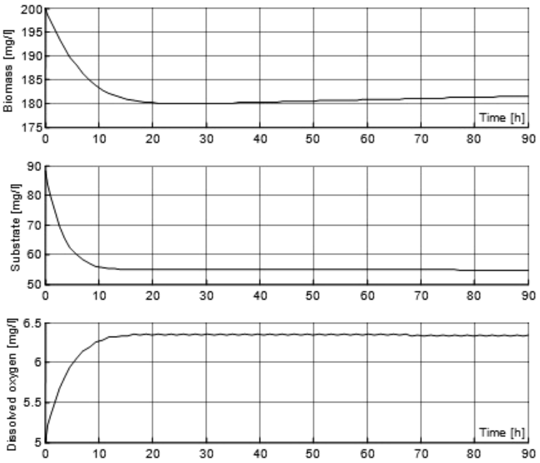

Fig.3. The systemic scheme of the wastewater treatment process

## 3. MULTIVARIABLE FUZZY CONTROLLER FOR THE WASTEWATER TREATMENT PROCESS SIMULATION RESULTS

Fuzzy theory was introduced by Zadeh in 1965. Fuzzy control algorithms use fuzzy logic to allow machines to make decisions based on the operator expertise. Fuzzy logic is a mathematical system that analyzes analog input values in terms of logical variables that take on real values between 0 and 1 (true and false).

The first applications in process control are attributed to Mamdani (1976) and they are based on the operator expertise. Practically, the human expertise is converted in rules, which is the rule-base of the controller. Research in human expert behavior have shown that its behavior is strongly nonlinear, with effects of anticipation, delays and even adapting to the concrete operating conditions. The refinement of the linguistic characterization and the interpretation of the control determining process can be done by choosing the parameters that can modify the fuzzy controller properties (Preitl and Precup, 1997).

Figure 4 presents the wastewater treatment process control system, where the output variables were controlled using quasi-PI fuzzy controllers.

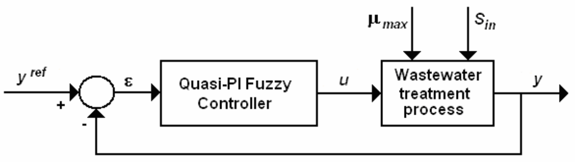

Fig.4. Wastewater treatment process control system

In figure 4, $y^{ref} = \left[DO^* \quad S^*\right]^T$, $u = \left[W \quad D\right]^T$ and $y = \left[DO \quad S\right]^T$.

Often, an easy way to control a fairly decoupled MIMO system is to use a multi-loop strategy (Kinnaert, 1995; Wittenmark, *et al.*, 1995). The pairing problem that quantifies the level of interaction occurring in the system was analyzed in (Chiroşcă, *et al.*, 2011).

The formalization of the rule base proceeds by max-min fuzzy composition rule of inference. The controller outputs are estimated by converting the internal fuzzy values into crisp ones using the gravity center the defuzzification method. This technique can be expressed as:

$$(6)\quad x^* = \frac{\int_x x\mu_i(x)dx}{\int_x \mu_i(x)dx}$$

where: $x^*$ is the deffuzified output, $\mu(x_i)$ is the membership function and $x$ is the output variable.

The complexity, non-linearity and time-varying parameters of the wastewater treatment process need to analyze the disturbance rejection and robustness problem.

The aim of the multivariable fuzzy control of the wastewater treatment process is to obtain an effluent having the substrate concentration within the standard limits established by law (in this application - below 20 mg/l).

The membership functions of the inputs (dissolved oxygen concentration error, dissolved oxygen concentration derivative error and substrate concentration) are presented in Figure 5. The membership functions of the outputs (aeration rate and dilution rate) are shown in Figure 6.

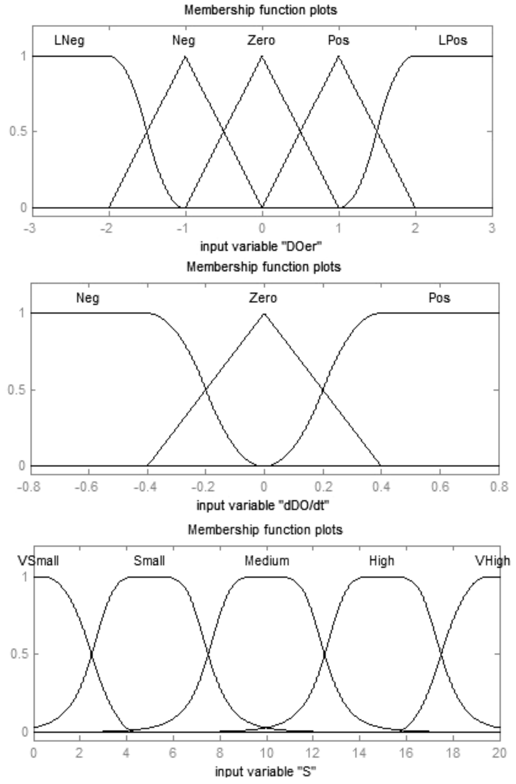

Fig.5. Inputs membership functions

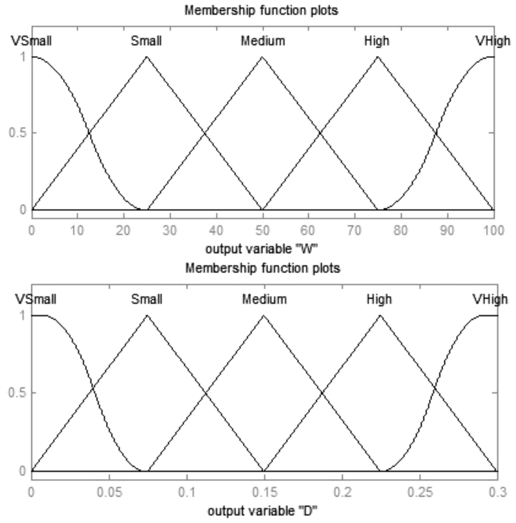

Fig.6. Output membership functions

The simulation results are presented in Figure 7, where DO setpoint was set to 2mg/l.

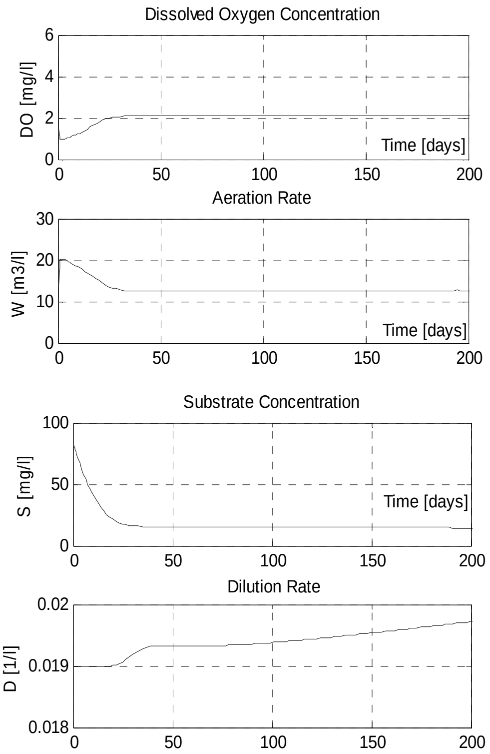

Fig.7. Simulation results of the multivariable fuzzy control of the wastewater treatment process

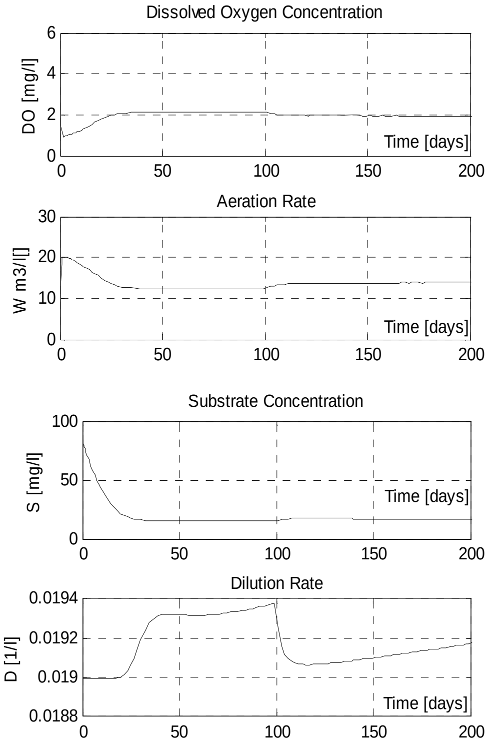

Fig.8. Disturbance rejection, when $S_{in}$ value has been modified from 200 mg/l up to 230 mg/l

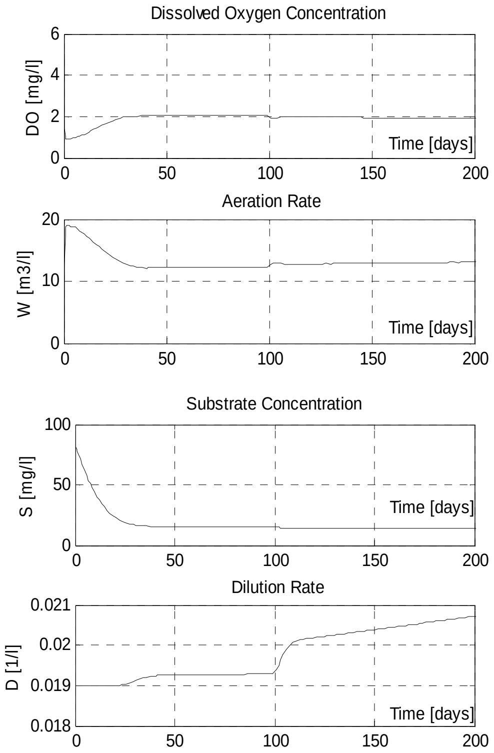

Fig.9. Uncertainty rejection, when $\mu_{\max}$ value has been changed from 0.15 up to 0.1725

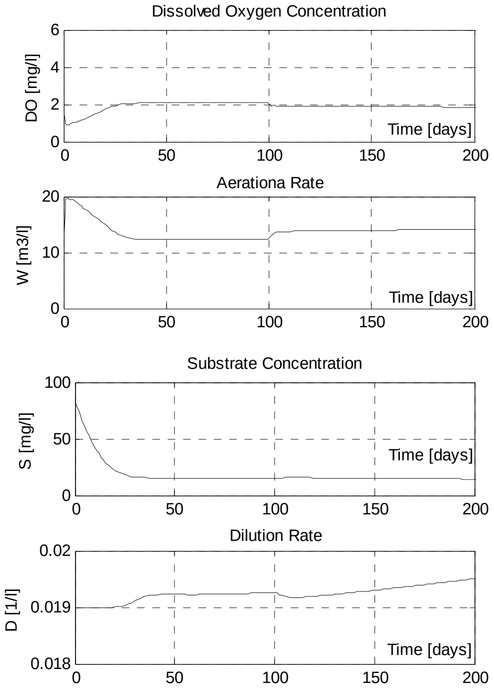

Fig.10. Disturbance and uncertainty rejection when $S_{in}=230mg/l$ and $\mu_{\max}=0.1725$

To analyze the problems of disturbance rejection and robustness, $S_{in}$ and $\mu_{max}$ values were increased about 15%, after 100 days.

The following cases were simulated:

1. At the time of 100 days, the $S_{in}$ value increases from 200mg/l to 230mg/l (DO setpoint has the same value - 2mg/l). The simulation results are presented in Figure 8.

2. At the time of 100 days, the $\mu_{max}$ value increases from 0.15 to 0.1725 (DO setpoint has the same value - 2mg/l). The simulation results are presented in Figure 9.

3. At the time of 100 days, the $S_{in}$ value increases from 200mg/l to 230mg/l and the $\mu_{max}$ value increases from 0.15 to 0.1725 (DO setpoint has the same value - 2mg/l). The simulation results are presented in Figure 10.

In all cases, the simulations have shown good results for step disturbance rejection and robustness analysis of the fuzzy control algorithm.

## 4. CONCLUSIONS

The wastewater treatment systems are complex, non-linear and multivariable processes. The present paper introduces a fuzzy controller and evaluates the control performances. The process involved, is treated as a MIMO process.

The process model utilized in this paper is a simplified model of wastewater treatment process aiming to reduce organic substances. The simulation experiment proves that fuzzy control can represent a reliable alternative to control wastewater treatment processes.

It was shown that, the design of the multivariable fuzzy controller, presented in this paper, provides good results in the analysis of the disturbance rejection and robustness performance. In this respect, two modifications have been made: both values of $S_{in}$ and $\mu_{max}$ were increased (about 15%). In all cases considered in simulations, the fuzzy controller of the wastewater treatment system has continued to track the imposed setpoint.

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