THE LINEARIZING CONTROL OF A WASTEWATER TREATMENT PROCESS WITH THE REMOVAL OF TWO SUBSTRATES

Sergiu CARAMAN, Marian BARBU and Eugen ARINTON

Department of Electrical Energy Conversion Systems,
"Dunarea de Jos" University, Domneasca 111, 6200 Galati, Romania
Phone/fax: +40 36 460 182, email: Sergiu.Caraman@ugal.ro

Abstract: This paper deals with the identification of a biological wastewater treatment process with the removal of two substrates. The identification has been done on the basis of experimental data supplied by Arcelor-Mittal Steel Company. For the identification of the wastewater treatment process with two substrates a criterion of distance type among the experimental data and the model outputs has been used. For the process control a linearizing structure based on the linearizing command principle has been adopted. The linearizing control algorithm has been check in the case of parametric uncertainties (the variation of the maximum specific growth rate parameter).

Keywords: wastewater treatment, process identification, linearizing control

1. INTRODUCTION

By wastewater we understand the water that is consequence of human activities whether it comes from industrial activities or household use or any other activity that leads to its degradation from its initial state. Before it can go back to its natural circuit, the wastewater must be treated (mechanical, chemical or biological treatment). The biological treatment takes place in treatment plants. The wastewater treatment is an important process and it gives us the certainty that man's impact on the use of the water is highly reduced. The aim of the wastewater treatment is to reduce the quantities of nitrogen, phosphorus, organic matter and solid matters in suspension.

The wastewater treatment process is a very complex process, strong non-linear and characterized by uncertainties regarding its parameters. In the literature there are many models that try to capture as closed as possible the evolution of the wastewater treatment processes with active sludge (Katebi, 1999), (Olsson and Chapman, 1985). The best known model in the literature is the one determined by a group of specialists from IAWQ (International Association of Water Quality) under the scientific guidance of professor Henze (Henze *et al*., 1987). The model proposed by this group is named ASM1 (Activated Sludge Model No. 1) and it contains the equations for organic carbon and nitrate removing. ASM1model has 13 state variables. Later the equations for phosphor removing were added to ASM1 model, the result being a more complex model named ASM2 with 19 state variables (Henze *et al*., 1995). After that the workgroup from IAWQ proposed another two developments of ASM2 model, named ASM2d and ASM3 (Henze *et al*., 2000). The main drawback of ASM1 model is its complexity, such that it becomes unusable in automatic control issues. The control of this multivariable non-linear process arouse big problems, the known achievements being related to the use of the artificial intelligence techniques (Nezam, 2002), (Cosmescu, 2003). These aspects lead to the trying of a simplified model use which allows the process control through classic techniques.

The paper is structured as follows: the second section describes the model of the process that has been used in control, the third section presents the identification procedure of the wastewater treatment process with the removal of two substrates, the fourth section deals with the linearizing control algorithm, the fifth section presents the behaviour of the control algorithm to the parametric uncertainties and the last section is dedicated to the conclusions.

2. THE MATHEMATICAL MODEL OF THE BIOLOGICAL WASTEWATER PROCESS WITH TWO SUBSTRATES

In the paper a simplified mathematical model for the two substrates removal (noticed S_1 and S_2) from the treated water will be used. The impurities from the wastewater consists in isocyanides and phenols for that the authors had experimental data from the company Arcelor-Mittal Steel Galati.

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

$$\frac{dS_1}{dt} = \frac{-\mu(t)}{Y_1}X(t) - (D(t)(1+r)S_1(t)) + D(t)S_{in1} \quad (2)$$

$$\frac{dS_2}{dt} = \frac{-\mu(t)}{Y_2}X(t) - (D(t)(1+r)S_2(t)) + D(t)S_{in2} \quad (3)$$

$$\frac{dDO}{dt} = -k_0\left(\frac{\mu}{Y_1} + \frac{\mu}{Y_2}\right)X(t) - D(t)(1+r)DO(t) + $$
$$+\alpha W(DO_{\max} - DO(t)) + D(t)DO_{in} \quad (4)$$

$$\frac{dX_r}{dt} = D(t)(1+r)X(t) - D(t)(\beta + r)X_r(t) \quad (5)$$

$$\mu = \mu_{\max}\frac{S_1(t)}{K_{S_1} + S_1(t)}\frac{S_2(t)}{K_{S_2} + S_2(t)}\frac{DO}{K_{DO} + DO} \quad (6)$$

where $X(t)$ – the biomass (sludge) in the aerated tank, $S_1(t)$- the concentration of the substrates 1, $S_2(t)$- the concentration of the substrates 2, $DO(t)$ – the concentration of the dissolved oxygen, $X_r(t)$ – the concentration of the recycled biomass, DO_{max} - the maximum concentration of the dissolved oxygen, $D(t)$ – the dilution rate, μ - the specific growth rate of the microorganisms, Y_1 - the production coefficient of the substrate $S_1(t)$, Y_2 - the production coefficient of the substrate coeficient $S_2(t)$, α – the rate of the recycled sludge, β – the rate of the removed sludge, μ_{max} - the maximum specific growth rate of the microorganisms, k_{S_1} - the saturation constant for the substrate $S_1(t)$; k_{S_2} - the saturation constant for the substrate $S_2(t)$, K_{DO} - the saturation constant for oxygen, K_O - model constant, W – the aeration rate, S_{in1} – the concentration of the substrate $S_1(t)$ in the inflow, S_{in2} – the concentration of the substrate $S_2(t)$ in the inflow, DO_{in} - the concentration of the dissolved oxygen in the inflow and r – the recycled sludge rate. Further on the model has been simulated using the following values of the coefficients and of the command variables (Figures 1-5): μ_{max}=0.2, Y_1=0.7, Y_2=4, k_o=0.7, k_{s1}=100, k_{s2}=100, k_{do}=2, β =0.4 α=0.15, DO_{max}=50; r=0.9, DO_{in}=0.5, D=0.065, W=70, S_{in1}=180, S_{in2}=230.

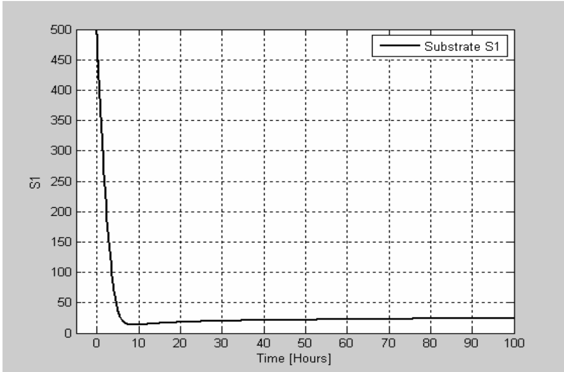

Fig. 1. The evolution of the substrate S_1

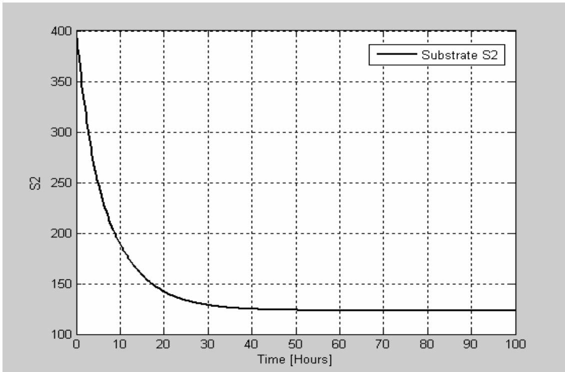

Fig. 2. The evolution of the substrate S_2

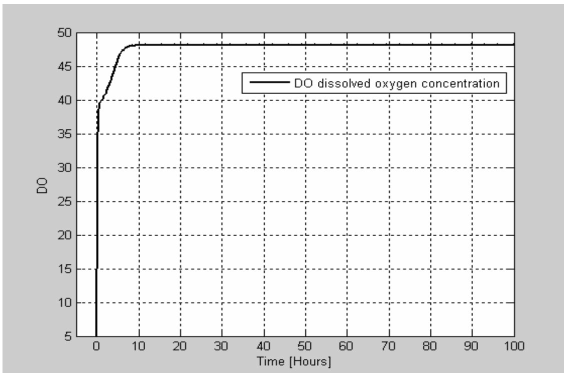

Fig. 3. The evolution of the dissolved oxygen concentration DO

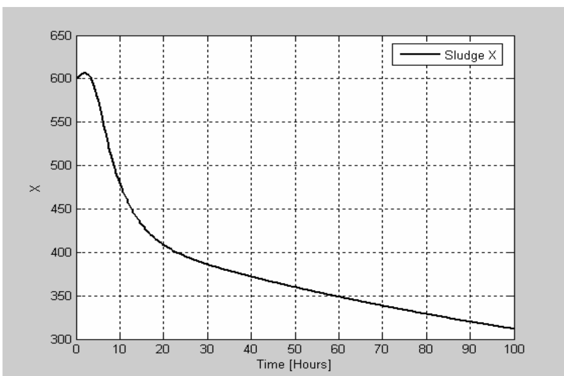

Fig. 4. The evolution of the sludge X

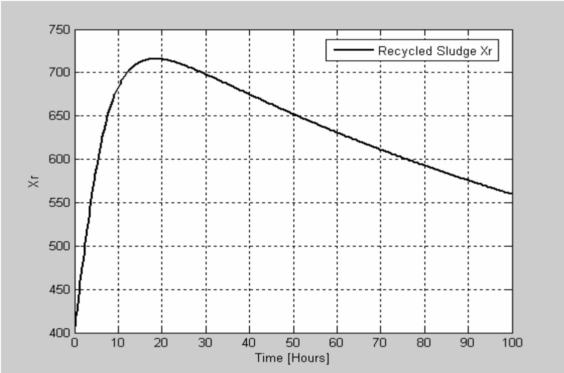

Fig. 5. The evolution of the recycled sludge X_r

3. THE IDENTIFICATION OF THE WASTEWATER TREATMENT PROCESS WITH TWO SUBSTRATES

For the identification of the wastewater treatment process with two substrates a criterion of distance type among the experimental data (the two substrates S_1 and S_2) and the model outputs has been used:

$$C = \sum_{N=1}^{20} \left[(S_1(N) - \hat{S}_1(N))^2 + (S_2(N) - \hat{S}_2(N))^2 \right] \quad (7)$$

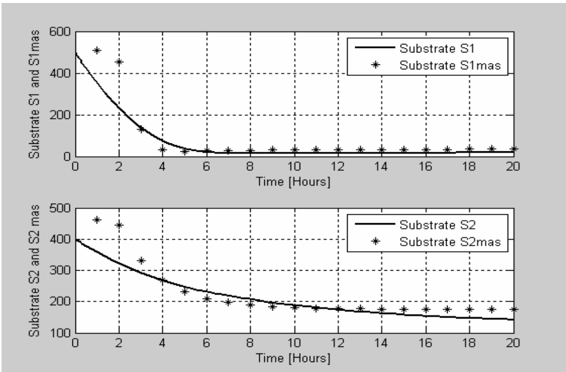

Fig. 6. The evolutions of the substrates S_1 and S_2 comparing to S_{1mas} and S_{2mas}

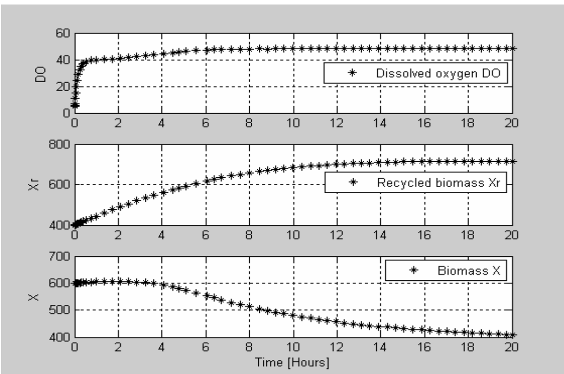

Fig. 7. The evolutions of the dissolved oxygen concentration DO, biomass X and recycled biomass X_r

The model parameters were determined through the minimization of the criterion C using a method of one-dimensional search type and they have the following values: μ_{max}=0.13, Y_1=0.55, Y_2=5.5, k_o=0.5, k_{s1}=105, k_{s2}=105, k_{do}=1.5, β =0.2, α=0.09, in the command conditions DO_{max}=50; r=0.9, DO_{in}=0.5, D=0.065, W=70, S_{in1}=180, S_{in2}=230.

The results obtained by numerical simulation are presented in Figures 6-7.

4. THE LINEARIZING CONTROL OF THE WASTEWATER TREATMENT PROCESS WITH TWO SUBSTRATES

For the control of the wastewater treatment process with two substrates a linearizing control structure has been adopted. The linearized command has been calculated according to the algorithm presented in (Bastin *et al.*, 1990)

Three cases were taken into consideration:

1. the control of the substrate S_1;
2. the control of the substrate S_2;
3. the control of both substrates S_1 and S_2.

<u>Case 1</u>: The linearizing command is given by equation (8):

$$u = \frac{\lambda_1 (S_{1ref} - S_1) + \mu \dfrac{X}{Y_1}}{S_{in1} - S_1 (1 + r)} \quad (8)$$

The simulation results are presented in figures 8-9 (the setpoint for the substrate S_1 is equal to 25mg/l):

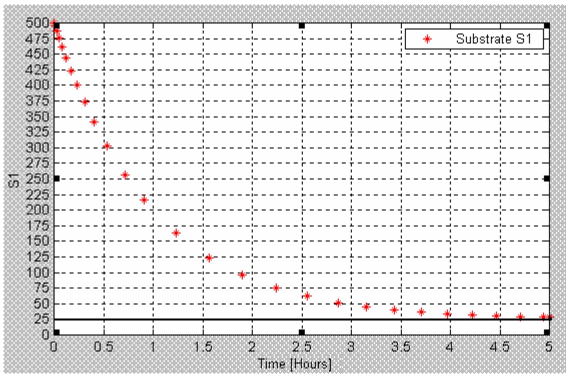

Fig. 8. The evolution of the substrate S_1 with the linearizing command

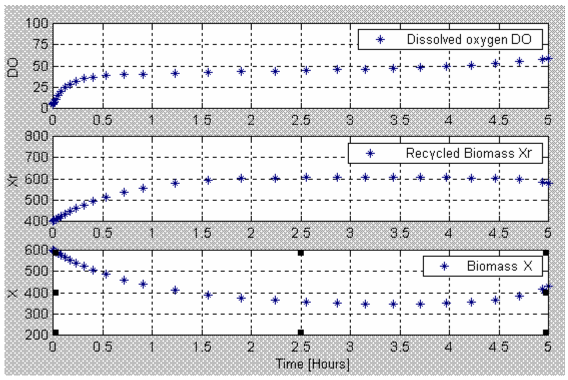

Fig. 9. The evolution of the dissolved oxygen concentration DO, recycled biomass X_r and biomass X with the linearizing command

Case 2: The linearizing command is given by equation (9):

$$u = \frac{\lambda_1 (S_{2ref} - S_2) + \mu \dfrac{X}{Y_2}}{S_{in2} - S_2 (1 + r)} \qquad (9)$$

The simulation results are presented in Figures 10-11 (the setpoint for the substrate S_2 is equal to 115mg/l).

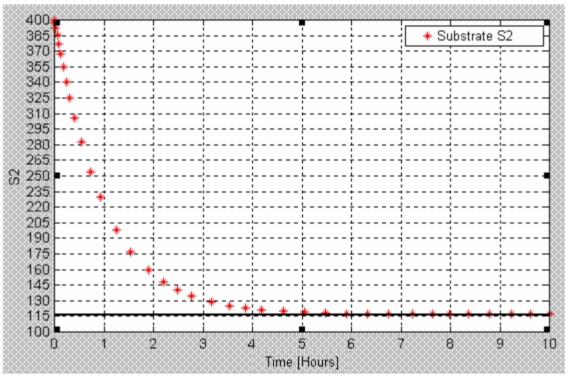

Fig. 10. The evolution of the substrate S_2 with the linearizing command

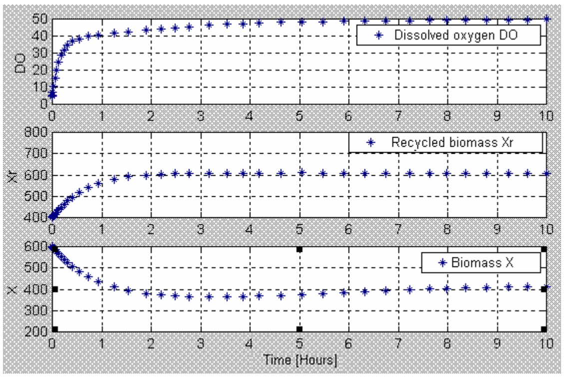

Fig. 11. The evolution of the dissolved oxygen concentration DO, recycled biomass X_r and biomass X with the linearizing command

Case 3: The linearizing control of the substrates S_1 and S_2 assumes the defining of a variable y as follows:

$$y = c_1 S_1 + c_2 S_2 \qquad (10)$$

where c_1=0.75 and c_2=1.25.

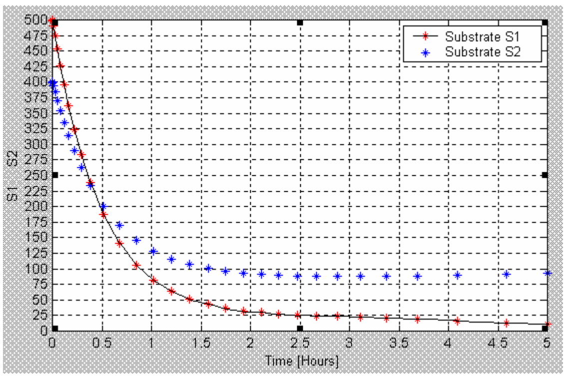

Fig. 12. The evolutions of the substrates S_1 and S_2 with the linearizing command

The linearizing command is given by equation (11):

$$u = \frac{\mu X \left(\dfrac{c_1}{Y_1} + \dfrac{c_2}{Y_2} \right) + \lambda_1 (y_{ref} - c_1 S_1 - c_2 S_2)}{c_1 S_{in1} - c_1 (1 + r) S_1 + c_2 S_{in2} - c_2 (1 + r) S_2} \qquad (11)$$

The simulation results are presented in figures 12-14 (the setpoint for the variable y is equal to 125mg/l).

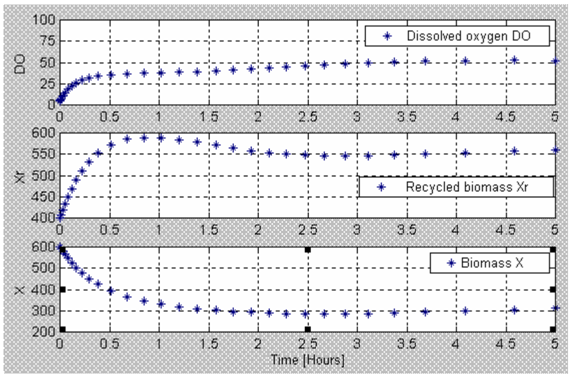

Fig. 13. The evolution of the dissolved oxygen concentration DO, recycled biomass X_r and biomass X with the linearizing command

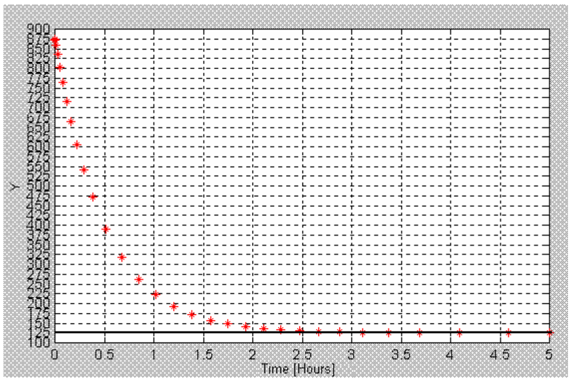

Fig. 14. The evolution of the variable y with the linearizing command

We must mention that the control of the variable y does not assure the control of the two substrates S_1 and S_2 independent from one another but only a global control of the two substrates.

5. THE ROBUSTNESS TEST OF THE LINEARIZING CONTROL ALGORITHM

The linearizing control structure has been check to the parametric uncertainties. The value of one of the most important parameters of the model - μ_{max} – was significantly modified. The three cases mentioned above were taken into consideration.

Case 1 (μ_{max}=0.13 becomes 0.2 after 3 hours):

The simulation results are presented in Figures 15 and 16.

Case 2 (μ_{max}=0.13 becomes 0.6 after 5 hours):

The simulation results are presented in Figures 17 and 18.

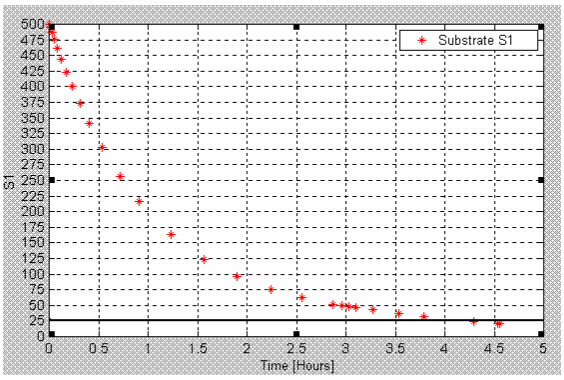

Fig. 15. The evolution of the substrate S_1 when the robustness of the control algorithm is check

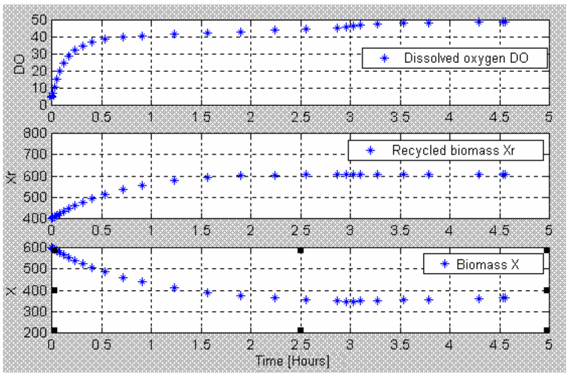

Fig. 16. The evolution of the dissolved oxygen concentration DO, recycled biomass X_r and biomass X when the robustness of the control algorithm is check

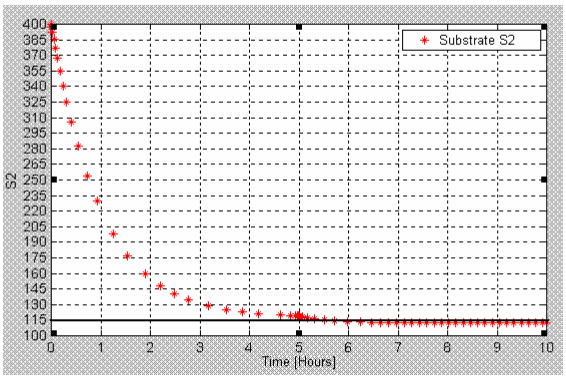

Fig. 17. The evolution of the substrate S_2 when the robustness of the control algorithm is check

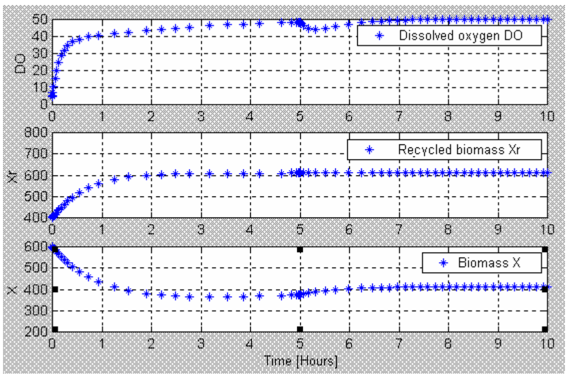

Fig. 18. The evolution of the dissolved oxygen concentration DO, recycled biomass X_r and biomass X when the robustness of the control algorithm is check

Case 3 (μ_{max}=0.13 becomes 0.6 after 2.5 hours):

The simulation results are presented in Figures 19-21.

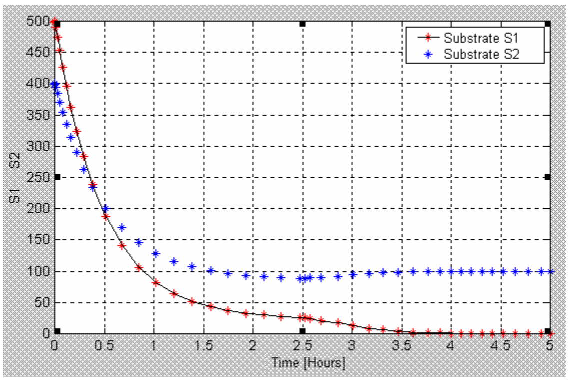

Fig. 19. The evolution of the substrate S_1 and S_2 when the robustness of the control algorithm is check

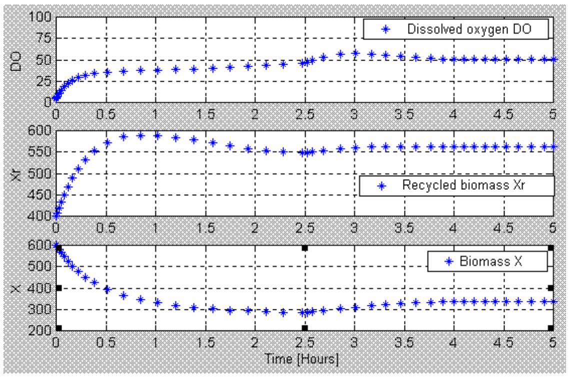

Fig. 20. The evolution of the dissolved oxygen concentration DO, recycled biomass X_r and biomass X when the robustness of the control algorithm is check

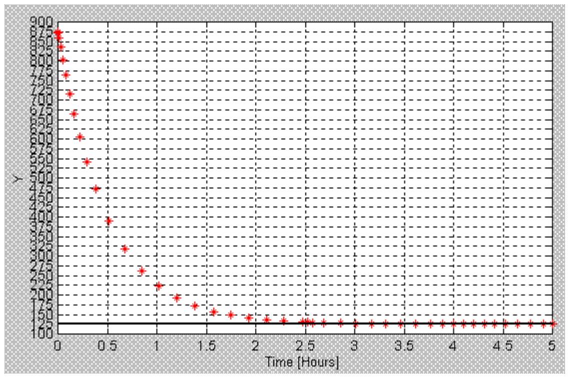

Fig. 21. The evolution of the variable y when the robustness of the control algorithm is check

6. CONCLUSIONS

In the paper a simplified model of the biological wastewater treatment process with two substrates has been adopted. However the model contains a great number of parameters that makes difficult its identification. Another difficulty for the model identification consisted in the small number of experimental data, the extension of the number of experimental data being necessary.

The linearizing control algorithm offers good results in the case of the two substrates removal. The robustness character of the linearizing control structure to parametric uncertainties has also been proved.

ACKNOWLEDGEMENT

The authors acknowledge the support of the Romanian National Education and Research Minister under CEEX-MENER Grant 717/24.07.2006 and of the Romanian National University Research Council under Grant GR 81/11.05.2007.

REFERENCES

Bastin, G. and D. Dochain (1990). *On-line Estimation and Adaptive Control of Bioreactors*, pp. 375, Elsevier.

Cosmescu, A.F. (2003) Hybrid neuro-fuzzy systems for the process control. PhD Thesis, Politehnica University of Bucharest, Romania.

Halvarsson,B. (2003) Applications of Coupling Analysis on Bioreactor Models. Msc Thesis, Uppsala University, Sweden.

Henze, M. et al. (1987) Activated Sludge Model No. 1. *IAWQ Scientific and Technical Report No. 1*, IAWQ, Great Britain.

Henze, M. et al. (1995) Activated Sludge Model No. 2. *IAWQ Scientific and Technical Report No. 3*, IAWQ, Great Britain.

Henze, M. et al. (2000) Activated Sludge Models ASM1, ASM2, ASM2d and ASM3. ISBN: 1900222248, IWA Publishing, Great Britain.

Katebi, M.R. Johnson, M.A., Wilke, J. (1999) Control and Instrumentation for Wastewater Treatment Plant. ISBN 1-85233-054-6, Springer-Verlag, Great Britain.

Nezam, N. (2001) Intelligent techniques for the wastewater treatment processes control. PhD Thesis, Politehnica University of Bucharest, Romania.

Olsson, G., Chapman, D. (1985) Modelling the dynamics of clarifier behaviour in activated sludge systems. *Advances in Water Pollution Control*, Pergamon Press.