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Modelowanie matematyczne, symulacja komputerowa i identyfikacja procesów dynamicznych i biologicznych w miejskiej oczyszczalni ścieków

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W Raporcie przedstawiono cztery artykuły zawierające wyniki badań w zakresie modelowania, symulacji komputerowej, identyfikacji i sterowania procesów technicznych i technologicznych zachodzących w mechaniczno-biologicznej oczyszczalni ścieków. Badania były prowadzone w ramach projektu badawczego KBN pn. Optymalizacja i sterowanie procesu technologicznego w mechaniczno-biologicznej oczyszczalni ścieków na podstawie modeli matematycznych.

Artykuły te, zgłoszone i przyjęte do publikacji w 2002 r., są następujące:.

1. *Von der Modellierung dynamischer Prozesse in Klaeranlagen (autorstwa J. Studzińskiego, L. Bogdan i Z. Nahorskiego), prezentowany na konferencji pn. Workshop zur Theorie und Modellierung von Oekosystemen, w Koelpinsee w Niemczech w br., i publikowany w książce pt. Theorie und Modellierung von Oekosystemen, w serii Umweltinformatik, wydawanej przez Shaker-Verlag w Aachen pod redakcją A. Gnaucka*
2. *Entwicklung eines Computersystems zur Modellierung, Simulation und Optimierung von Klaerprozessen in Klaeranlagen (autorstwa J. Studzińskiego, J. Łomotowskiego, L. Bogdan, Z. Nahorskiego i R. Szeteli), publikowany w książce pt. Theorie und Modellierung von Oekosystemen, w serii Umweltinformatik, wydawanej przez Shaker-Verlag w Aachen pod redakcją A. Gnaucka*
3. *Wastewater treatment plant maintenance using the plant mathematical models (autorstwa J. Studzińskiego), przyjęty do prezentacji i publikacji w materiałach konferencji pn. Qualiy, Reliability and Maintenance – QRM'2002, w Oxfordzie w Anglii w 2002 r.*
4. *Modelowanie matematyczne, identyfikacja i sterowanie mechaniczno-biologiczną oczyszczalnią ścieków (autorstwa L. Bogdan, J. Łomotowskiego, Z. Nahorskiego, J. Studzińskiego i R. Szeteli), zgłoszony i przyjęty do publikacji w książce wydawanej w 2002 r. przez IBS PAN pod redakcją J. Gutenbauma.*

Spis treści

Wastewater Treatment Plant Maintenance Using the Plant Mathematical Models

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ABSTRACT

Two kinds of mathematical models of the activated sludge process developed for a real wastewater treatment plant are presented. One kind of the model called *physical model* is described with the use of ordinary differential equations. This model is destinated for computer simulation of the wastewater treatment process and for verification of the plant controls generated with the second kind of the model. This one is called *operative model* and is described with the neuronal nets. The operative models are less detailed than the physical ones but they are much faster by the computer solution what makes the optimization calculation more effective.

INTRODUCTION

The usual maintenance of the wastewater treatment plants consists in stabilizing different unit processes with conventional automation. This way of acting is not satisfactory in many cases when the amount and composition of the wastewater inflow is changing periodically and in large ranges. It seems that then the use of mathematical models for prediction of the process states and generation of the process controls could be more effective than the application of the classical PID type controllers. Using ordinary differential equations resulted from physical, chemical, and biological principles and described transformations of wastewater components we can formulate a *physical model* of the overall treatment process. Models of this kind are very complex and their direct use in control of plants is quite inefficient for they require big calculation times to solve any optimization task. However, these models can be very useful in examination of the control signals that could be obtained in another way. One simulation run of the physical model does not take much time and is enough to proof the rightness of the predicted controls before they will be applied to maintain the process. On the other hand there is convenient to use some *operative models* to carry out all optimization problems. The mathematical descriprion of these models is simply and they are less detailed but also much faster than the physical ones. They can be applied to predict the inflow of the raw wastewater and the state of the purificated wastewater on the output of the plant and also to generate the controls of the process. The physical model presented in this paper belongs to the class known in the literature as the Activated Sludge Model No. 1 [1]. This kind of models describes wastewater processes with degradation of organic and nitrogen components. The operative models presented here are formulated with the use of neuronal nets.

1. WASTEWATER TREATMENT PLANT AND THE MAINTENACE SYSTEM

Figure 1 shows schematically the modelled wastewater treatment plant. In Figure 2 the idea of a complex computer system to maintain the plant using two kinds of its mathematical models is shown. The treatment process occurs as follows [4]: The wastewater enters the primary clarifiers where settleable solids settle down while the rest of the wastewater flows to the activated sludge basins equipped with an aeration system. The organic material is decomposed there biologically under aerobic conditions. The mixed liquor from the aeration tanks passes to the secondary clarifiers where the sludge is separated from the treated wastewater by means of gravitational settling of the sludge particles. Part of the sludge is recirculated to the inlet of the aeration basins while the excess sludge is removed from the process for further treatment.

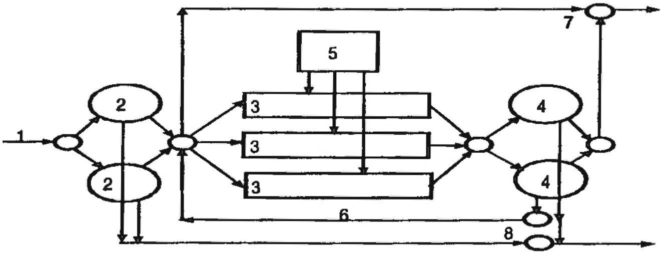

Figure 1. Diagram of the wastewater plant: 1 – wastewater inflow; 2 – primary clarifiers; 3 – aerations basins; 4 – secondary clarifiers; 5 – aeration system; 6 - extern recirculation; 7 – outlet of the purificated wastewater; 8 – outlet of the raw and activated sludge.

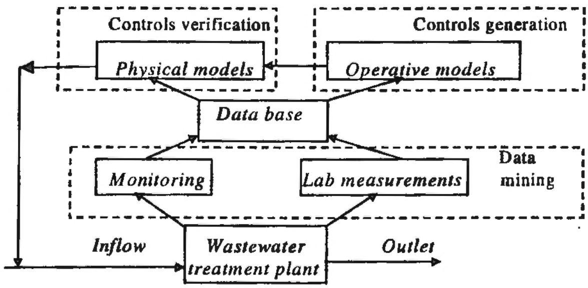

Figure 2. Diagram of the computer system to maintain the wastewater plant

3. PHYSICAL MODEL AND ITS CALIBRATION

The physical model consists of several submodels of the basic plant vessels treated as the ideally mixed tanks where physical and biological processes occur. Often only part of the vessel geometric volume (called *active volume*) is engaged in flow dynamics and the active volume may differ significantly from the geometric one. To calculate these active volumes the hydrological models of all vessels have been created and the linear regression was applied to estimate the models (see Table 1). The data used for estimation of the active volumes were gathered during an active experiment in which chlorine ions (produced from the salt added to the wastewater inflow) were used as the tracer [3].

Table 1. Estimates of the active volumes of the vessels, in [m^3].

	Primary clarifiers	Aeration basins	Secondary clarifiers
Calculated volumes	5.676	11.246	11.026
Geometric volumes	7.820	13.500	11.060
Calculated/Geometric [%]	72,6	83,3	99,7

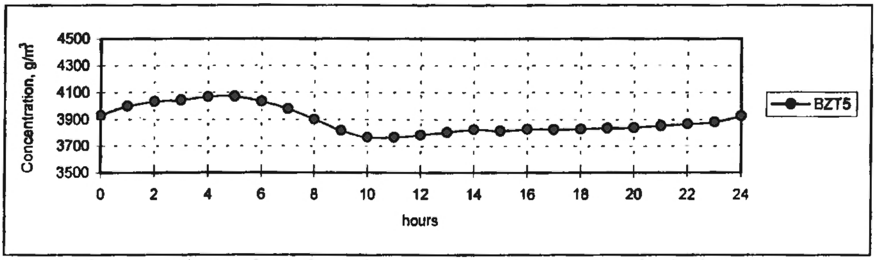

Figure 3. Measured (*line*) und calculated biomass concentration in the aeration basins.

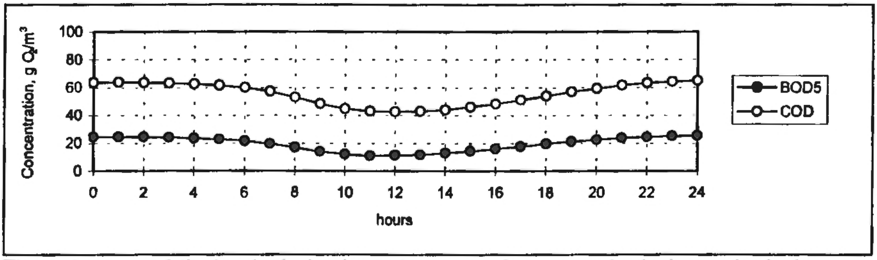

Figure 4. Measured (*line*) and calculated organic compounds concentration in the aeration basins.

The complex model of the wastewater treatment includes the separated submodels of primary clarifiers, aeration basins and secondary clarifiers, together with the appropriate connections between them (see Figure 1) [3]. The wastewater components are divided into different fractions and their concentrations in the particular vessels can be calculated by the apriopriate submodels from the measurements taken at the plant. In the submodel of primary clarifiers the COD (Chemical Oxygen Demand) and nitrogen fractions are concerned and divided into dissolved and suspended components. The dissolved fractions pass the primary clarifiers without any loss but because of sedimentation of the suspension the resulted concentrations of COD and nitrogen are reduced. The submodel of aeration basins includes all transformations recorded before and also the change of the oxygen concentration and alkalinity of the wastewater. The influent entering the secondary clarifiers from the aeration basins consists of flocculated bacteria and water and the submodel of these objects describes the separation of these two components in the sedimentation process. The model developed is overspecified (the number of its parameters exceeds the number of measured variables) and it was impossible to obtain unique values of the kinetic and stoichiometric model parameters using classical numerical techniques. Thus the model was calibrated using the human expert method, based on professional experience and expertise [2]. The obtained fit of the model is quite satisfactory (see exemplary results in Figures 3 and 4).

4. OPERATIVE MODEL

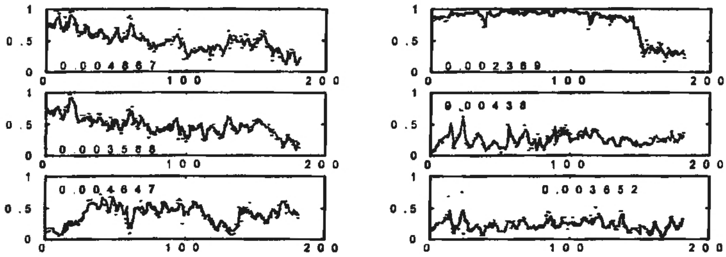

Figure 5. Training the network for six output parameters (*points - data, line - network*).

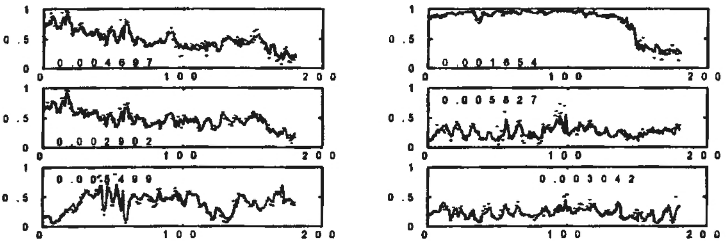

Figure 6. Testing the network for the same process parameters as in Figure 5.

To develop an operative model using a neural net the same wastewater data were used as for the physical model calibration. The neural net identified is a backpropagation network consisted of three layers with twelve neurons on the first layer, six neurons on the hidden layer and with six neurons on the output one. As the input of the network act the following sewage parameters measured at time t: wastewater inflow; BOD (Biological Oxygen Demand), ammonia and suspension concentrations of the raw sewage; oxygen concentration in the aeration basins; recirculation flow; activated sludge concentration and activated sludge drop ability in the aeration basins; recirculated sludge concentration; BOD, ammonia and suspension concentrations of the sewage purificated, while as the network output act the output parameters of the plant measured at time $t+T$ and these are the latter six parameters of the previous list. A quite well correspondence between the data and the network has been received (see Figures 5 and 6).

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