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Fuzzy Adaptive Control of Dissolved Oxygen in a Waste Water Treatment Process

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Abstract: The general idea behind the wastewater treatment procedure is to obtain an effluent having the substrate concentration within some standard limits. This purpose can be satisfied by controlling the concentration of dissolved oxygen to a certain value. In this work, we consider a simulation study of a fuzzy adaptive control for a concentration in a bioreactor. A Takagi Sugeno (TS) fuzzy inference system (FIS) is used to approximate the feedback linearization law, and the parameters are updated based on a fuzzy estimation. The test system is a wastewater treatment plant and the objective is to control the dissolved oxygen (DO) concentration levels in the activated sludge process which is one of the major processes in a wastewater treatment plant. The results obtained are compared with other works.

Keywords**:** Activated sludge, adaptive control, bioreactor, dissolved oxygen concentration, fuzzy systems, wastewater treatment process.

1. INTRODUCTION

In general, a wastewater treatment plant separates solids from the liquid, and consists of two basic stages: primary treatment and secondary treatment (Rosemount, 2009). In the primary treatment stage, larger solids are removed from wastewater by settling. Secondary treatment is a large biological process for further removal of the remaining suspended and dissolved solids. Secondary treatment removes up to 85% of the remaining organic material through a biological process of cultivating and adding sewage microorganisms to the wastewater. This process is accomplished in a trickling filter or an aeration tank.

Plants use aeration tanks to suspend microorganisms in wastewater. After leaving the primary treatment stage, sewage is pumped into aeration tanks. The sludge is loaded with microorganisms and mixed with air or pure oxygen. As air is forced into the aeration basins, it increases the activity of these microorganisms and helps keep the organic waste thoroughly mixed. Dissolved oxygen (DO) is added to the aeration basin to enhance the oxidation process by providing oxygen to aerobic microorganisms so they can successfully turn organic wastes into inorganic byproducts.

The wastewater is treated in order to obtain an effluent having the substrate concentration within some standard limits. This goal is achieved by controlling the concentration of DO to a certain value. The control of DO concentration is important because this concentration must be kept above a critical level in order to supply enough oxygen to maintain the microorganism activity. Therefore, control of the DO at the critical level will result in efficient use of energy. Wastewater treatment processes are characterized by several dynamic features, e.g. large influence flow rate variations and changes in the concentration of influent substrate concentrations and pollutants. The dissolved oxygen concentration in the bioreactor is a key manipulated variable. Its set point trajectory prescribed by the upper control layer is forced in the reactor by an aeration system that delivers an oxygen by blowing airflow Q into the bioreactor. Different control strategies for the waste water treatment process have been investigated. Firstly, in (Ju Ko *et all.,*1982), an adaptive controller for the DO process has been given and it has been shown that it is possible to obtain on-line estimates of the mass transfer coefficient and oxygen uptake rate. in (Brdys *et al.,* 2007), a hierarchical multilayer control structure that utilises multiple time scales in the plant dynamics for robust optimised control of the biological wastewater treatment plants was proposed.

Successful control of the DO process has been obtained by using classical PID control. However, the application of artificial intelligence adaptive control has the advantages that it facilitates the implementation to control the DO concentration levels in the activated sludge process which is one of the major processes in a wastewater treatment plant. In

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(Han *et al.,* 2008), a softly switched Takagi-Sugeno nonlinear PI controller has been derived.

Fuzzy logic systems and artificial neural networks have been widely used as adjustable components in adaptive control. In particular, fuzzy systems are introduced to approximate unknown nonlinear functions in nonlinear systems in the form of linear regression with respect to unknown parameters and then to apply the well developed adaptive control techniques. Two methodologies have been used, the direct and the indirect methods. In the indirect method, the fuzzy system is used for approximating the unknown nonlinear functions appearing in the model while in the direct method, the fuzzy inference system approximates the control law as a whole.

In the vast majority of proposed fuzzy and neural adaptive control approaches, the tracking error is used as the adaptation signal. Nonetheless, based on the idea of supervised learning, a few authors have suggested to use the control error as the adaptation signal. However, since the ideal (target) control signal is unknown, the approach is not directly applicable. So, we suggest to estimate this control signal through a Mamadani type fuzzy estimator, and then the parameters updates are then computed using this estimation.

In this work, we consider a simulation study of an adaptive fuzzy control for nonlinear systems. A Takagi Sugeno (TS) fuzzy inference system (FIS) is used to approximate the feedback linearization law. The adaptation mechanism is based on an estimate of the error between the ideal unknown control signal and the actual control signal. This estimate is provided by a Mamdani fuzzy system whose rule base is constructed using simple expert reasoning. The parameters of the TS controller are updated using the gradient descent law based on the estimated control error. The test plant is the DO in water treatment plant and the objective is to control DO concentration levels in the activated sludge process. The results obtained are compared with other works.

This work is organized as follows: section 2 describes the wastewater treatment process, in particular the activated sludge process, section 3 describes the proposed fuzzy adaptive controller scheme and in section 4, a simulation results are presented to show the effectiveness of the proposed method.

2. DESCRIPTION OF THE WASTEWATER TREATMENT PROCESS

2.1 Dynamics of the dissolved oxygen

A typical wastewater treatment plant as described in (Ju Ko *et all.,*1982) consists of an aerator and a separator as shown in (Fig. 1).

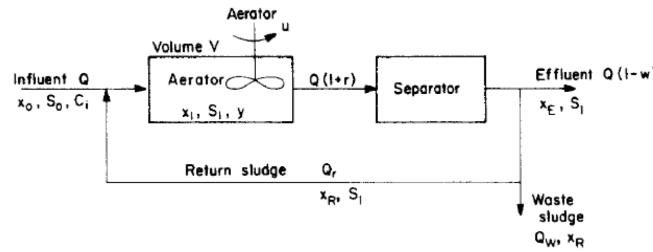

Fig. 1. The wastewater treatment process

where the following symbols are used: Q, flow rate; w, ratio of waste flow to influent flow; r, ratio of recycled flow to influent flow; x, microorganism concentration; S, substrate concentration; y, dissolved oxygen concentration in aerator vessel; C_i, influent dissolved oxygen concentration; C_s, maximum dissolved oxygen concentration; and u, air flow rate. In the aerobic environment of the aeroator in which oxygen is injected via compressed air, microorganisms react with the organic material in the wastewater and with the oxygen dissolved in the water to produce more cell mass, carbon dioxide, and water.

The effluent of the aerator flows to the separator where the activated sludge is separated from the liquid phase. A portion of the concentrated sludge is recycled in order to maintain enough mass of viable organisms and the remainder of the settled sludge is discarded. The process effluent consists of the overflow from the separator tank. As described in (Ju Ko *et all.,*1982), a simplified model for the process can be obtained assuming that the DO concentration is sufficient to maintain biological activity.

2.2 Aerator

$$\frac{dx_1}{dt} = -\frac{1}{V}.(1+r).Q.x_1 + \frac{1}{V}.r.Q.x_R - K_D.x_1 + \mu.x_1 \tag{1}$$

$$\frac{dS_1}{dt} = -\frac{1}{V}.(1+r).Q.S_1 + \frac{1}{V}.Q.S_0 + \frac{1}{V}.r.Q.S_1 - \frac{\mu}{K_Y}.x_1 \tag{2}$$

where the symbols are as in Fig. 1, together with K_D, organism endogenous decay rate; μ, growth rate defined as $\mu = \hat{\mu}.S_1/(S_1 + K_S)$; with $\hat{\mu} = y(t)/(y(t) + K_c)$, maximum growth rate; K_S, saturation coefficient); and K_Y is a yield coefficient.

2.3 Separator

From a mass balance on the separator we obtain

$$(r+w).x_R + (1-w).x_E = (1+r).x_1 \tag{3}$$