Energy efficiency in activated sludge process using adaptive iterative learning control with PI ABAC

Maimun Huja Husin[1], Mohamad Faizrizwan Mohd Sabri[1], Kismet Anak Hong Ping[1], Norazlina Bateni[2], Shamsiah Suhaili[1]
[1]Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Sarawak, Malaysia
[2]Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Sarawak, Malaysia

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ABSTRACT

This paper proposed an iterative learning control (ILC) with a feedback regulator based on proportional integral ammonium-based aeration control (PI ABAC) to improve dissolved oxygen control through data learning of iteration data. The proposed controller's performance is evaluated using benchmark simulation model no. 1. (BSM1). The assessments focused on four main areas: effluent violation, effluent quality, aeration energy, and overall cost index. The proposed ILC PI ABAC controller's effectiveness is evaluated by comparing the performance of the activated sludge process to the BSM1 PI and feedback PI ABAC under three different weather conditions: dry, rain, and storm. The improvement of the proposed method over BSM1 PI is demonstrated by a reduction in aeration energy of up to 24%. In conclusion, if the proposed ILC PI ABAC controller is given enough information, it can be quite successful in achieving energy efficiency.

Corresponding Author:

Maimun Huja Husin
Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Malaysia Sarawak
94300 Kota Samarahan, Sarawak, Malaysia
Email: hhmaimun@unimas.my

1. INTRODUCTION

Access to clean water is a necessity for both humans and the environment. Maintaining water supplies and guarding the nature for a sustainable future is the most important contribution of wastewater treatment plants (WWTPs) to protecting public health. To achieve this, more stringent effluent regulations have been established for WWTPs. These stricter requirements force WWTP operators to improve their control strategies. The main issue for WWTP operators is to reduce operating costs, especially energy for aeration while maintaining high effluent quality. Aeration is an energy-intensive process where energy consumption can be as high as 67.2% [1]–[3]. Wastewater quality discharged into rivers from treatment plants that do not meet standards is subject to a fine.

Advanced control systems have proven to be a practical solution to the above problem to improve wastewater quality discharged and minimize energy use compared to traditional proportional, integral and derivative (PID) controllers. However, advanced control systems like model predictive control (MPC), need a strong predictive model to forecast the plant’s future response. It is challenging to develop good predictive control because the biological process of wastewater treatment is extremely complex, confusing, and unexpected. Modelling the activated sludge process is also complicated by issues of nonlinearity, fluctuations in influent flow, and significant disturbances [4]–[7].

Proportional-integral (PI) controls are the traditional controls that are still routinely employed to control the activated sludge process in WWTPs. This is primarily due to the significant expense of upgrading the control system of the existing WWTPs. The use of PI controllers in most WWTPs has been due to their simplicity, durability, and near-perfect control. However, with the introduction of new wastewater standards, the conventional PI controller is no longer capable of adapting to changing operational conditions in the WWTP. When using the PI controller, a compromise must always be made between aeration energy and effluent quality. If the aim is rather to improve the quality of the wastewater, the cost of aeration energy is high [8]–[11]. Moreover, a typical PI controller is not able to cope with the problems of nonlinearity, fluctuation of influent and severe disturbance in the treatment plant [12]–[15].

Several studies have been conducted over the last decade to assess the effectiveness of various control methods that use dissolved oxygen (DO) to reduce aeration expenses. The feature of this control system is the availability of a DO sensor probe that can continuously measure the DO levels in the tank. The primary concept behind employing the DO sensor probe is to regulate the DO supply based on the oxygen requirement of the microorganisms in the tank. However, this technique has flaws because it is impossible to identify the exact value of the microorganism's actual oxygen consumption at any given time. As a result, the majority of the proposed DO control schemes have increased the DO set point to avoid nitrification failure. However, even with the DO control technique, aeration costs remain an issue because DO control necessitates aerators and turbines powered by electric motors, which add to the system's costs. This necessitates a paradigm shift in the methods used to address the issues of energy consumption and aeration control costs. This issue has been investigated, and a solution is provided in which the aeration process can be regulated by modifying the DO set point based on the ammonium nitrogen (SNH) concentration in the wastewater [16]–[18].

Ammonium-based aeration control (ABAC) is a control strategy that uses SNH as a response variable in addition to or instead of DO. ABAC is a method that helps improve effluent quality while keeping aeration energy low by using real ammonium measurement [19]–[24]. The study shows that the neural network ABAC reduced aeration energy by up to 23% while improving wastewater quality by 1.9% [19], [21]. Up to 43% of the aeration cost can be saved in [22]. The impact of ABAC on energy consumption is observed after a comprehensive implementation of ABAC at a regional water treatment plant, which achieved an average energy savings of 5%, equivalent to an average savings of 10% in total electricity costs per month [23].

Despite the fact that ABAC has been on the market for a number of years, most pilot or real-world plants employ the PI controller in their ABAC configurations. The PI controllers used are set up to be disseminated. This arrangement is advantageous because the coupling problem in a multiple-input multiple-output (MIMO) system is avoided. A PI controller, on the other hand, is infamous for being prone to interference and/or operational state variations. On the other hand, several investigations have demonstrated that sophisticated control systems outperform PI controllers. MPC, for example, is known to be computationally demanding [25]–[27]. As a result, a leaner control method with less complexity is preferable, particularly if the controller will be utilized in a real or pilot plant.

To increase the effectiveness of the control system by providing an adjustment system that helps to deal with the nonlinearity of the wastewater inflow, an iterative learning control (ILC) is introduced in this study. ILC is a type of tracking control that allows the system to operate in a recurrent mode. There are very few published results on the implementation of ILC in WWTPs [5], [28]–[30]. The data-driven indirect ILC scheme was suitable for the case where no mechanistic model of the complex system was available [30]. The learning control algorithm can gradually enhance the performance of the tracking control for the next runs by applying ILC, which effectively uses the data from past iterations, surpassing conventional control systems such as feedback controllers and model predictive control [5]. The proportional iterative learning control (P-ILC) algorithm is employed in the aeration basin of oxygen input connection with consideration of data producing omission by altering the algorithm to totally regulate the aeration tank of oxygen, obtaining the best wastewater treatment efficiency [29].

In this study, a combination of ILC and PI ABAC is proposed with the aim that the proposed controller can better adapt to the changes in the inflow. To verify the efficiency of the proposed controller, its performance is evaluated with two other control configurations, namely the standard benchmark simulation model no. 1 (BSM1) PI [31] and the feedback controller PI ABAC [8].

2. METHOD

BSM1 consists of 5 activated sludge reactors with two anoxic basins and three aerobic basins. A secondary clarifier follows the active sludge reactor. Figure 1 depicts an in-depth diagram of the BSM1 plant. The basic control technique for BSM1 is to first manipulate the internal recycling flow rate to control nitrate