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Quantitative evaluation of A^2O and reversed A^2O processes for biological municipal wastewater treatment using a projection pursuit method

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ABSTRACT

In this work, a new model was developed to quantitatively evaluate and compare anaerobic/anoxic/aerobic (A^2O) and reversed A^2O processes for municipal wastewater treatment using projection pursuit method based on particle swarm optimization (PSO). The optimal projection direction was obtained by optimizing the projection index function using the PSO algorithm. By fitting the logistic equation, the evaluation model was established. Then, the calculated ranks of the evaluation samples were computed. The overall performance of both A^2O and reversed A^2O processes were evaluated using the established model as a case study. The results show that the mean rank of the A^2O process (1.79 ± 0.39) was lower than that of the reversed A^2O process (1.97 ± 0.41), indicating that the former was better than the later under the same operating conditions. Through resolving multi-factor evaluation problems, such a PSO-based model is demonstrated to be effective to quantitatively assess wastewater treatment processes.

1. Introduction

In municipal wastewater treatment plants (WWTPs), activated sludge process is usually used for the simultaneous biological removals of nitrogen, phosphorus and organic carbon substances. Currently, anaerobic/anoxic/aerobic (A^2O) process is the most widely used biological nutrient removal system because of its cost-effectiveness and high efficiency [1–5]. In A^2O process, the anaerobic phase is placed in the front of the anoxic phase, and organic substrate in wastewater is sequestered by phosphorus accumulating organisms under anaerobic conditions, resulting in a low or even no availability of organic substrate for denitrifiers under anoxic conditions [6–8]. As a result, the denitrification performance of the A^2O process is sometimes poor [2]. To resolve this problem, anoxic/anaerobic/oxic (reversed A^2O) process was proposed by placing anoxic stage before anaerobic stage [8–10]. Compared to the A^2O process, the reversed A^2O process could exhibit more complete denitrification and improve phosphorus uptake by bacteria under aerobic conditions [9–11]. Furthermore, by eliminating the mixed liquor recirculation required in the A^2O process, the reversed A^2O process is easier to manage and reduces the infrastructure investment and operating costs [10–12]. However, some researchers claimed that the elimination of mixed liquor recirculation in the reversed A^2O process could lead to a reduced nitrogen removal, because nitrogen removal by denitrification became solely reliant on the flow of the returned activated sludge [10]. These two processes have their own advantages and disadvantages for the nutrient removal from municipal wastewater. In this case, practical tests or model simulations should be conducted to evaluate the suitability of the two processes for WWTP.

However, practical test is usually time-consuming and costly. Moreover, it is often incapable of taking into account the possible changes in the process, such as influent quality, influent quantity, and operating parameters. By contrast, mathematical modeling and computer simulation, as a valuable evaluation tool, show overwhelming advantages under such circumstances and offer a useful and more efficient means to evaluate the complex systems [13,14]. Thus, it is necessary to develop a mathematic model to quantitatively evaluate the two processes for municipal wastewater treatment.

Since evaluation of both A^2O and reversed A^2O processes is a multi-factor problem, an efficient method should be found to transform multi-factor problem into a single-factor one. Projection pursuit (PP) has been used as an exploratory data analytical technique of multivariate data [15,16]. It is a linear mapping that projects high-dimensional data into a low-dimensional space via a projection index [17–19]. The optimal projection direction could be obtained by maximizing the projection index that describes the inhomogeneity of data [20]. With the optimal projective direction, the evaluation model could be constructed and used for evaluating the A^2O and reversed A^2O processes.

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However, obtaining the optimal projection direction in PP is a complex nonlinear optimization problem. Therefore, particle swarm optimization (PSO) approach was chosen for resolving the problem due to its simple rules, high accuracy, and fast convergence rate, compared with other optimization methods, such as genetic algorithm [21]. PSO is one of the evolutionary stochastic optimization algorithms based on the social metaphor of bird flocking or fish schooling [22]. PSO is an optimization tool by providing a population-based search procedure, in which individuals, called particles, change their positions with time. In a PSO system, particles fly around in a multidimensional search space. In flight, each particle adjusts its position according to its own experience and the experience of neighboring particles, making use of the best position encountered by itself and its neighbors. The PSO method has been applied in various fields [23–27], and could be used to solve the complex nonlinear optimization problem in PP.

Therefore, the main objective of this study is to develop a mathematic model to quantitatively evaluate the two biological wastewater treatment systems, A^2O and reversed A^2O processes, with a PP evaluation model based on PSO algorithm. The performance of a full-scale WWTP, in which both A^2O and reversed A^2O processes were used to treat municipal wastewater, was compared.

2. Materials and methods

2.1. Description of the WWTP

This work is based on the operational data from the Qinghe WWTP in Beijing, China. This WWTP was designed for removal of chemical oxygen demand (COD), nitrogen and phosphorus from municipal wastewater. In this plant, half of wastewater (200,000 m^3/day) is treated by the A^2O process, consisting of an anaerobic tank, anoxic tank and aerobic tank (Fig. 1). The hydraulic retention times (HRTs) of the anaerobic tank, anoxic tank and aerobic tank are 1.5 h, 2.5 h and 10 h, respectively. In this process, a large fraction of the settled activated sludge (secondary sludge) is returned to the anaerobic tank to maintain the desired sludge level. The mixed liquor recirculation and the returned activated sludge recirculation ratios are set at 300% and 80% of influent flux, respectively. Another half of wastewater (200,000 m^3/day) is treated by the reversed A^2O process, which consisted of an anoxic tank, anaerobic tank and aerobic tank (Fig. 1). The HRTs of the anoxic tank, anaerobic tank and aerobic tank are 1.5 h, 2.5 h and 10 h, respectively. In the reversed A^2O process, only one external return system exists, in which the settled activated sludge is partially returned to the anoxic tank to maintain sludge level, and the sludge recirculation ratio is set at 80%.

2.2. Wastewater characteristics

The influent COD, 5-day biological oxygen demand (BOD_5), suspended solids (SS), total nitrogen (TN), NH_4^+ and total phosphorus (TP) concentrations of the A^2O process and reversed A^2O process of the WWTP during 1-year operation period are summarized in Table 1. The average concentration COD, BOD_5, SS, TN, NH_4^+ and TP in the influent were 472, 235, 280, 66.1, 52.3, and 6.56 mg/L, respectively.

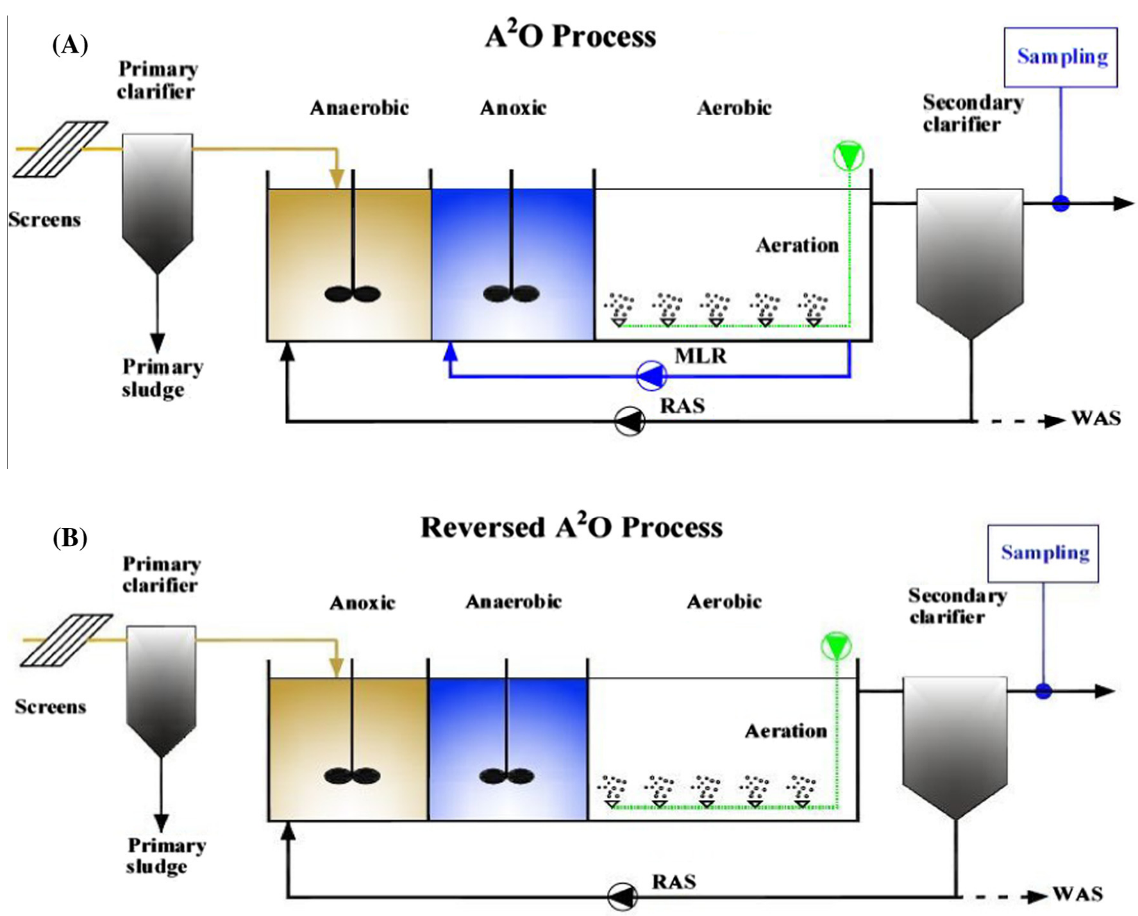

Fig. 1. Schematic of the two biological nutrient removal processes: (A) A^2/O; and (B) reversed A^2/O.