Research Progress on Modelling of Activated Sludge Process in China

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Abstract. In the past ten years, the research of Chinese scholars in the process modelling of activated sludge process mainly focused on the following aspects: Applicability diagnosis and evaluation of existing models in practical problems, improvement of parameters and models, the application of simulation technology in modelling, and development of new combinatorial models, etc. This paper aims to grasp the future trends of related research through a clear understanding of the research progress.

1. Introduction
Activated sludge is essentially a symbiotic system of bacteria micelles and filamentous bacteria. Its main bacterial group is Proteobacteria[1]. The effect of treating organic wastewater under aeration conditions was significant, and it also showed certain ecological restoration functions, which can be widely used in the treatment of water pollution.

As early as the end of the 19th century, foreign scholars had begun to study the mathematical model of sewage treatment. In 1949, Monod [2] tried to explain the growth process of bacteria with quantitative data and further improved the "Monod formula". After the 1980s, the Activated Sludge Model series models were launched by the International Association of Water Quality (IAWQ). Since the models included carbonation, nitrification, denitrification and other processes as well as dissolved oxygen, heterotrophic organisms, and autotrophic organisms and other components, they were widely used.

Although the corresponding research in China started late, with the improvement of automation control technology, intelligent control theory and integrated control theory, the simulation models of the theoretical model in the sewage treatment were getting higher and higher, and then more mature in the prediction and control. The static mathematical model theory for the activated sludge process has been developed for more than 70 years. Based on the research and improvement of scholars, and timely feedback of relevant business activities [3], the models can quickly adapt to the situation of wastewater treatment in China. Although there were many nonlinear and uncontrollable factors in the actual processing process, the simulation and prediction results of the models were not significant, their research prospects were still broad. The following will review the operation diagnosis and evaluation of some mainstream activated sludge mathematical models in practical applications.

2. Activated Sludge Model Series Models
The development process of ASM series models issued by the International Association Water Quality (IAWQ) is shown in Table 1 below.
Table 1 ASM series model development process

| Characteristic | Theoretical basis | Common point |
|----------------|-------------------|--------------|
| ASM1 (1986)    | It can simulate the dynamic properties of carbon removal and denitrification in activated sludge process. | Death - regeneration, maintenance | All models use differential equation groups to describe the process dynamics; ASM series models belong to the mechanism model; and each local model is used to restore the overall dynamic changes of the actual wastewater treatment system. |
| ASM2 (1995)    | It can simulate the dynamic properties of decarbonization, denitrification and phosphorus removal in activated sludge processes. | Endogenous microbial respiration |
| ASM3 (1999)    | It can simulate the dynamic properties of carbon and nitrogen removal, excluding phosphorus removal. |

Although the mathematical model of activated sludge has been continuously improved, each model has its own characteristics. In addition, the wastewater treatment systems in practical problems are complex and variegated, all these models cannot be completely replaced with each other in practical applications. Therefore, all these mainstream models have developed derivative models. In order to reduce errors, researchers use the ASM series models often based on reasonable assumptions that the simulation object is currently operating normally. However, it is worth noting that the sensitivity of the parameters of the ASM series model will vary with the weather. Even if the optimum model was obtained through calibration, strictly speaking, it can only be used under the current weather conditions of the correction. At present, most simulation experiments were taken at 20°C. However, in practice, the temperature changes will inevitably lead to the error of the kinetic parameters. These problems are challenging the promotion of models [4-5].

2.1. ASM1 model

In the optimization and transformation of the urban wastewater treatment plant, after the analysis and verification of the sensitivity of the parameters, the water quality model based on the ASM1 model had a good simulation effect. ASM1 model could describe instantaneous dynamic changes and the removal of a variety of restrictive contaminants, and it was also a more complete biological reaction kinetic model[6]. Considering the effect of sludge retention time on the treatment process, good results were also obtained in the simulation experiment of anoxic-aerobic denitrification process (A/O) [7]. ASM1 also showed great adaptability to series combination systems: by virtue of its descriptive performance over the Lawrence-McCarty model, the improved, calibrated compound empirical model will also be quantified and refined in the future [8]. To further improve accuracy, biomass changes and model corrections need to be considered [9]. However, the water quality parameters of the initial model did not include the phosphorus removal processes, in addition, the additional assessment of the ability to remove phosphorus from activated sludge was too troublesome. Therefore, in practical application, the problems of the model were gradually exposed, and the promotion and application were limited.

2.2. ASM2 model

Inheriting the structure of the initial model, supplementing the components that described phosphorus removal, ASM2 was released in 1995. The ASM2 model involved too many components, splitting the activated sludge system into many fine parts, and solving the overall dynamics through each local calculation. In the Phoredox process, A2/O phosphorus removal process and other practical applications, the simulation results were very satisfactory [7].

The second-generation derivative model ASM2d was more complex due to the addition of indicators that described phosphorus removal and nitrification and denitrification. In the six-tank integrated process optimization problem that can only reach the periodic steady state [10-11], ASM2d simulated
the biochemical reaction cell section. This improved model had good predictive performance for effluent water quality [12-13], could simulate substrate removal rates under different conditions, also could intuitively observe and select the optimum mixture reflux ratio, sludge return ratio, and other factors [14-15]. In the actual transformation of the actual phosphorus removal process played a strong guiding role, so that the effluent of companies met the updated wastewater discharge standards [16]. The ability of ASM2d to simulate nitrates and phosphates had been further strengthened. It had shown good adaptability in actual sewage treatment cases[17].

The second-generation model, especially the derivative ASM2d, is currently the mainstream model used for biological phosphorus removal simulation in China and even in the world. However, some treatment plants contain chemical substances that inhibit the growth of microorganisms in the influent or treatment process, which may inhibit the phosphorus removal process. This leads to cost and utility problems in the implementation of the activated sludge process and the maintenance of the use of ASM to optimize the retrofit process[18].

2.3. ASM3 model
ASM3 is a model for the direct improvement of the initial model. It pays more attention to the storage process of organic materials but does not add phosphorus indicators. Since this model has not been in existence for more than two decades, research on its performance efficiency is still in the exploratory stage [19].

The A/O denitrification process simulator based on ASM3 instead of ASM1 is not very effective. Although the relative error of steady-state and dynamic simulation can be controlled within 30%, this figure is still too high, and the relative error at individual sampling points is even as high as 112.45%, which is far beyond the acceptable range of the wastewater treatment plant [20]. In order to solve the problems caused by the three-generation model, some amendments proposed to consider from the microbiological point of view. Some researchers also held that the errors can be reduced in the prediction and simulation of electron acceptors in the case of microbial growth and nutrient deficiency[21].

An improved FCASM model (Full-Coupled Activated Sludge Model) based on the ASM3-Bio-P module of the phosphorus removal module was added. Due to the addition of the switch function, the nitrification reaction was effectively suppressed, and the simulation of the biological growth cycle was prolonged. Simulation experiments at sewage treatment plants in Deqing County and other places showed that this model was more complete and closer to the actual situation than the previous models [22]. After combining the phosphorus metabolism mechanism and meso-mechanism, the fully coupled second-generation model FCASM2 and the third-generation model FCASM3 appeared one after another. In addition to the gradual increase in the simulation effect, FCASM3 also directly coupled temperature as a variable into the equation to visually represent the effect of temperature on the biological response, preliminarily solved the temperature problem that ASM series models could not break [23-24].

3. Intelligent model
The intelligent control in the sewage treatment mainly adopts the black box model, while the activated sludge series model takes into account the biological reaction factors, and the principles of the two are quite different.

In terms of technical operation, artificial neural networks show absolute advantages, without having to go through complicated algorithms, but through the input of data, parallel computing and analysis by multiple processing units, and continuous approximations and actual simulation values are obtained. At present, in the neural control, the relatively mature and most widely used is the error back-propagation BP network model [25]. After training the model by using the inflow and outflow data and process parameters, the simulation results of the ozone biological activated carbon system at Daqing Petrochemical General Plant met the actual situation [26]. To expand the applicable surface of the model, it is necessary to use a large amount of data for training, so as to achieve accurate prediction of different water quality and achieve on-line control of different treatment plants.
Due to the unavoidable shortcomings of a single intelligent control model, multiple exploration models have been developed, such as the combination of neural networks and process mechanism models, as well as the combination of intelligent control models [27].

Researchers used activated sludge process mechanisms combined with neural networks to propose a gray box model of hierarchical neural networks. This further identifies the stability of the algorithm and has important implications for complex series processes [28]. In the process of water purification, the characteristic model ANFIS combined with fuzzy logic and neural network is introduced. After more than a hundred iterations, it has a more stable predictive simulation performance than the BP model can achieve the effect after more than a thousand iterations. Obviously this adaptive fuzzy neural network is more developed [29].

4. Insufficiency and outlook
In recent years, the links between various disciplines and professions have become increasingly closer. While the rapid development of the mathematical model of activated sludge, the intervention of simulation technology has played an important role in model correction and optimization. However, there are still many unsolved problems:

(1) The ASM series model was established based on the activated sludge method. Due to the limitations of microbial growth conditions, this series of models was not applicable to industrial wastewater. (2) The scope of application of most ASM models is limited to the mainstream part of the wastewater treatment process. Sewage treatment is a typical non-linear problem, with its complexity and variability, which leads to a wastewater plant to establish many matching models at different stages of the process. There are contradictions and differences in the mechanism and structure between different model systems, which require a very high demand for the knowledge of the sewage plant technicians. (3) Although the artificial neural network model can approach the complex and nonlinear activated sludge treatment process, in the current success researches, the main training data often comes from the data of a certain processing plant in a short period of time; In addition, due to the model does not have the ability to store empirical knowledge, long-term or large-scale data training can easily lead to unexpected local extremum. (4) Most of the existing software haven’t incorporate sludge disposal into the design, so it is difficult to achieve overall optimization.

Even though the application of artificial intelligence has been increasingly reflected in the modelling process, it is still too early to truly realize full-simulation and intelligent operation. At present, some scholars have begun to try mathematical modelling of the entire sewage treatment plant, combine two or more intelligent control technologies with modelling, intelligent control and model control in order to be able to break through these problems as soon as possible.

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