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The Current Status and Development Trend of Wastewater Treatment Technology in the Era of Artificial Intelligence for Society

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ABSTRACT

Wastewater treatment technology plays a key role in the process of water environment protection as well as the sustainable development of human society. In the era of artificial intelligence (AI) for society, employing various wastewater treatment technologies to enhance the wastewater treatment efficiency economically and intelligently is of huge importance. To that end, this paper reviews the current status and development trend of wastewater treatment-related technology and its future trend against the backdrop of AI for society. The synergy of wastewater treatment technology and AI is the development trend for water and wastewater industry. Since the future is here, so various AI technologies should be leveraged in almost all sectors inclusive of wastewater treatment industry to boost the efficiency and empower the sustainable development goals as well.

KEYWORDS: wastewater treatment technology, pollutant, influent, effluent, artificial intelligence for society, smart wastewater treatment management system

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1. INTRODUCTION

With the fast pace of industrialization and urbanization in human society, the demand for water and wastewater treatment service has increased accordingly. To meet this growing demand, especially the treatment of wastewater and its recycled reuse, which have drawn the attention of stakeholders including the academic community, the water industry, and the general public. At present, given the development of AI technology for society, there are various wastewater treatment technologies, namely physicochemical method, biological method, and hybrid method in general [1]. Specifically, physicochemical methods comprise membrane technology, adsorption, and oxidation process; biological methods include activated sludge process (ASP), anammox, bioremediation, and phytoremediation; while hybrid method is the combination of the former two methodologies. Regarding the term AI, it was by Marminski who first coined the term at the Dartmouth conference in 1956. Nonetheless, there is no universal definition of AI. Essentially, it is believed that artificial intelligence is the study of how to enable computers to do intelligent work that only humans can do in the past. From 2022 onwards, we have entered the large language model (LLM) era, particularly in 2024 and 2025, the respective prevalence of OpenAI and DeepSeek, featuring in large scales, massive training data, and multimodality. This paper summarized the status of wastewater treatment technologies and there associated applications in real world as well as the future development trend in the context of AI for society (AIS). It is worth mentioning that AIS is an integral part of AI, only that the former underlies the real application of AI technology for society, because not all users or consumers need to take time to learn the in-depth computer science or relevant majors.

2. CURRENT STATUS OF WASTEWATER TREATMENT TECHNOLOGY

Wastewater treatment is a complicated process, requiring physical, physicochemical, and microbiological technologies depending on the dynamics fluctuations of influent over time and corresponding effluent standards and multifold purposes as well. At present, the commonly used concrete wastewater treatment technologies include but not limited to anaerobic-aerobic reactors [2], biogas codigestion[3], biological denitrification [4], hydrothermal carbonization technology [5], anaerobic digestion technology [6], the anaerobic-anoxic-oxic (AAO) membrane bioreactors process [7], to name only a few. Notably, each wastewater treatment technology has its own merits and demerits, thus should be employed according to the real circumstances.

By utilizing the aformentioned wastewater treatment technology in one way or another, most wastewater treatment plants (WWTPS) can achieve their goals of multi-pollutant removal efficiency, to be specific, the concentrations of chemical oxygen demand (COD),

five-day biochemical oxygen demand (BOD5), ammonia nitrogen (NH3-N), total phosphorus (TP), total nitrogen (TN), and suspended solid (SS) can suffice for the standards of effluent quality as required.

So far, due to the constraint of capital budge or other cost control consideration, not many small and medium sized water and wastewater treatment plants have put the AI technology into large scale use. The application of AI technology is no new in water and wastewater management system. In fact, from 1940s onwards, the "ancestor" of AI, namely artificial neural network (ANN) and expert systems (ES) has been developed and optimized for a variety of real-world applications. Apart from ANN and ES, so far, a large school of AI variants have emerged, for example, genetic programming, which can be applied without preliminary assumptions on associated model structure; for another example, fuzzy logic with the characteristics of easy reasoning procedure alongside mimicking human thinking; other striking AI technologies cover support vector regression, particle swarm optimization, random forest, self-organizing map, K-nearest neighbor, and adaptive neural fuzzy inference system, the list goes on[8].

Since 1980s, the model of systematic WWTP has been introduced to enhance pollutant removal efficiency, followed by online just-in-time process observations technique, for instance, the facility of instrumentation, control, and automation [9]. In the meanwhile, decision tree, gradient boosting, genetic algorithms, and machine learning are widely used as well [10].

On top of that, the concept of smart water management system (SWMS) has been introduced in municipal water supply and drainage management. SWMS is akin to internet of things (IoT), With the further development of AI for society, it has been extended to the wastewater treatment process, thus facilitating the procedures of data collection, computation and analysis of effluent quality and enhancing the operation efficiency ultimately [11]. The efficiency for wastewater treatment plants in this paper mostly refers to the reduction of energy consumption, incurred cost, among others.

3. DEVELOPMENT TREND OF WASTEWATER TREATMENT TECHNOLOGY

The future is here. AI has reshape the entire world thus far. Like almost any other sector, wastewater treatment industry is also massively impact by the development of AI technology. In case of smart wastewater management system, which is the future trend for wastewater treatment industry, it is simply a fashion of AI technology, which uses online monitoring devices including data acquisition instruments, wireless networks, and water quality and water pressure meters to perceive the operation status of urban water supply and discharge systems in real time. It can automatically integrates wastewater management departments and water supply and discharge facilities in a visual way to construct a "wastewater management Internet of Things".

Meanwhile, wastewater management Internet of Things can swiftly analyze and tackle considerable water management information and provide targeted processing results as well as decisive countermeasures. This way, the AI agent can manage the whole production, management as well as service processes of the wastewater system in a dynamic way to achieve a "smart" state.

4. CONCLUSION

In the ear of AI, it is critically important to take advantage of AI to empower the entire human society, in particular, AI can be the enabler for boosting efficiency in wastewater treatment sector. In that sense, the paper explored the status and future development of wastewater treatment technology and application. No doubt that in the context of AI, every unit, particularly the wastewater treatment plants, in our case, should actively embrace the advanced AI technology, combine the professional wastewater treatment technologies with AI such that to improve wastewater treatment efficiency via improving the accuracy of data accuracy and pinpointing existing problems and the targeted solutions accordingly. This way, one can maximize the positive spillover effect of AI in water and wastewater treatment industries.

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