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Commentary

A Review of Wastewater Treatment Plant Modelling: Revolution on Modelling Technology

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Abstract: This review paper deals with the previous and current wastewater treatment plant modelling. The future of semantic modelling in a wastewater treatment plant through a new approach, Artificial Immune Systems (AIS), is introduced. AIS is still in the infant stage of soft computing. However, it has gained its popularity in the recent years, especially in prediction modelling. The first dynamic model of the activated sludge system was developed in the 1970s, and has been further developed since then. The process of a wastewater treatment is very complex, non-linear and characterised by many uncertainties within the influent parameters. The operation of a wastewater treatment process is limited because it is affected by variety of physical, chemical, and biological factors. A review of the wastewater modelling development was presented. The models' limitations were identified and a new technique in wastewater treatment plant is finally discussed.

Keywords: Activated Sludge, Artificial Immune System, Modelling, Revolution, Wastewater Treatment Plant

1. Introduction

In the era of globalisation, wastewater management is important to protect our environment from deteriorating. The government has spent millions of ringgit to build treatment facilities to treat the sludge as compared to constructing centralised wastewater treatment plants. In practice, the stakeholders and engineers are always trying to find solutions to satisfy both the environmental and economic criteria. Despite significant efforts, progress of sanitation targets is very slow and still lacking behind [1].

A major investment is required in order to set up a wastewater treatment plant due to high capital cost, operation and maintenance cost [2]. Based on the previous studies, a small and isolated villages or settlements with low population densities can be served by decentralised systems that are simpler and cost effective [3] [4] [5] [6]. However, it requires proper operation, maintenance, and good understanding of the process involved.

Computer science has become a norm in engineering perspective since 1970s. In 1974, the first dynamic model of an activated sludge system was developed [7] to gauge the performance of the system. Wastewater treatment plant modelling is constructed in a simple manner and yet produced the true process behaviour. In short, modelling is a simplification of reality of a wastewater treatment plant. A mathematical modelling on activated sludge process had started in the 1982 by the International Association on Water Pollution Research and Control (IAWPRC). In the 1980s, a declarative modelling has been suggested as a remedy for the 'black box' nature of self-contained models [8] [9] [10] [11]. The declarative modelling was integrated with graphical as self-explanatory models such as Simile [12] and STELLA [13]. This approach is relevant to modelling process but it does not show the long term model's output which is important to measure the effectiveness of the treatment processes.

At the present stand, the prediction of effluent removal from the wastewater treatment plant in the long run is not being investigated. The objective of this review paper is to promote a new approach in the wastewater prediction modelling process. It will briefly review the methodologies and tools for various types of uncertainty assessments. As such, it touches the aspects of model development through the AIS application.

2. Revolution of Wastewater Treatment Model

The operation, control and supervision of a wastewater treatment plants were approached from many different points of view, including classical control methods [14] [15] [16] [17], mechanistic models [18] [19], knowledge-based systems [20] [21] [22], case-based reasoning [23], neural nets [24] [25], hybrid approaches [26] [27] and hydraulic model [28]. As time flies, the soft-computing techniques are introduced. The commonly used networks in modelling and prediction of wastewater treatment process are the Feed-Forward Neural Network [29], Regression Support Vector Machine [30], Artificial Neural Network [31], Fuzzy Logic [32] [33] [34] and presently using Recurrent High Order Neural Network [35]. Currently, a new approach- the AIS was developed in wastewater modelling [36] [37]. In short, through modelling this could increase the affordability of wastewater management systems.

The most widely applied computer simulation of activated sludge process is the Activated Sludge Model (ASM) 1 [18] created by a group of International Association of Water Quality. The ASM 1 was further developed in 1995 by introducing nitrogen and phosphorus removal to establish ASM 2 [19]. The model was further improved into ASM 2d in 1999 where denitrifying phosphorus-accumulating organisms were included [38]. The developed model need not heavily require nitrogen removal processes. In the same year a new platform was developed called ASM 3 which introduced an internal storage compound [39]. The storage compound is important for metabolism of the organisms and considered carbon and nitrogen removal. ASM 3 was further developed into ASM 3C where the organic state variables are expressed in terms of organic carbon. According to Henze *et al.* (2000) [40], future development is required towards the improvement of the models by looking into the storage phenomena and model's trust on real scenarios and complex modelling.

The wastewater modelling is a challenge due to its complex, non-linear processes and uncertainties influent parameters [41]. The wastewater treatment started with the development of a steady state model that includes the hydraulic model [28]. In the study, he developed a full-scale data on mass balances. However, the model depends entirely on dynamic data which might encounter problems with the real input variables which are usually faster than the slow process during the steady state calibration.

In addition, modelling a treatment plant is hardly visible although several techniques applied show significant good result. Activated sludge systems are the most extensively used in wastewater treatment plants [42]. The system operates under aerobic conditions whereas alternating systems require a periodical change from aerobic conditions to anoxic conditions. In a conventional activated sludge system, the processes of equalization, biological treatment, and secondary clarification will be accomplished by using separate tanks [43]. The modelling approach applied is mostly based on pilot study or lab scaled experiments as actual treatment plant is not modelled [44]. Based on a study by Huang *et al.*, in 2010 [45], efficient operations of a wastewater treatment process are limited due to variety of physical, chemical and biological factors. Moreover, trying to model a natural system containing living organisms is unforeseeable.

On the other hand, wastewater treatment modelling requires frequent sampling for more accurate modelling [46]. Nevertheless, measurements on full-scale effluent removal are relatively expensive. Study carried out by Ye *et al*. (2009) [47] clarifies that effluent quality is the most important criterion of wastewater treatment plant. However, lack of suitable process variables, limits the effective control of effluent quality [48]. Prediction on quality of effluent discharge provides us the opportunity to measure the effectiveness of treatment processes carried out at the plant. This would enable us to obtain useful information for a better control of the entire infrastructure. In addition, the establishment of the prediction effluent management model can be used as a decision making tools [49].

3. The Immune Systems Approach

As mentioned in Section 2.1, wastewater treatment is a complex nonlinear biological reaction process. It is difficult to obtain reliable kinetic parameters and the prediction of wastewater treatment is not exact. The intelligent algorithms are able to establish a complex system model. Nevertheless, it was found that the prediction error varied slightly over the range of data sizes used in training and testing [50]. Furthermore, the modelling of wastewater treatment observed a large learning assignment, slow convergence, and local minimum in the neural network [51] [52]. The immune systems exhibited properties such as robustness, adaptability, learning, memory, recognition, feature extraction, diversity, scalability and multiple interactions on a variety of timescales [53] [54].

Inspired by the theories and observed principles of the immune system and applied towards solving the computational problems, wastewater treatment modelling is simulated using the actual condition. The immune system is considered to provide both defence and maintenance of the body [55] which is similar to the biological process in a wastewater treatment plant. According to Enezi *et al.* (2010) [56], the immune system usually works on two mechanisms namely, the innate immunity and the adaptive immunity. It assigns dynamically the immune memory unit and antibody population according to the Antibody-Antibody and Antibody-Antigen affinities. The advantages are that the system provides ergodic and dynamic properties of the treatment processes and introduces a chaotic search mechanism to improve its search efficiency. The immune systems work like a computational machine that transforms body states data into immune-system data while simultaneously providing feedback on the body to modify its state and restore a healthy state [57]. Thus, this will eliminate the complexity of wastewater treatment process and the 'black-box' of other soft computing modelling.

4. AIS Modelling Concepts

AIS is a computational paradigm which is inspired by theoretical immunology, observed immune functions, principles and mechanisms [58]. AIS-based algorithms mimic the human immune system's characteristic of learning and adaptability. The primary advantages of the AIS are the fact that it only requires positive examples, and the patterns it has learnt can be explicitly examined [59]. Furthermore, an AIS constitutes intelligent methodologies that were used to churn effective solutions to the real world problems [60] and perform a wide range of tasks in various engineering applications [61] [62]. This is proven when a full scale of a septic sludge treatment plant has successfully applied AIS in the effluent prediction modelling [37] [49].

The AIS approach is able to recognise the pattern of effluent removal of a wastewater treatment plant and clone the pattern to optimise and further predict the system outputs. Despite of this, the AIS is a bio-inspired computational model that uses idea and concepts from the natural immune system as mentioned above [63]. It also implements a learning technique inspired by human immune system which is a remarkable natural defense mechanism that learns about foreign substance. The main concepts are the interaction between antigen and B-cells (stimulation and suppression). It involves cloning and mutating processes [64]. The AIS methodology can be obtained from previous studies [36] [37] [39]. It can offer a strong and robust information processing capabilities for solving complex problems.

5. Conclusion

In the last decade, the AIS approach has emerged. A computational intelligence technique of the AIS is the new revolution in wastewater treatment plant modelling. As explained and reviewed above, the AIS application can overcome limitations in the complex environment like wastewater treatment processes. Stimulation, suppression, cloning and mutation are the main application areas in an AIS model. Currently, the model is applicable to septic sludge treatment plant but can be adopted to other situations. The second part of this paper focused on the limitations of wastewater modelling. Previous studies were based on experiment and scaled model of wastewater treatment plant using controlled input variables. The new proposed approach has successfully been applied to actual treatment plants [37] [49]. The major contribution obtained from this review is the fact that the AIS technique can be used as a decision and informative tool to reduce uncertainty of effluent discharge. This approach will allow stakeholders and design engineers to decide on the suitability of wastewater treatment plant for future development and enhancement.

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