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WATER QUALITY PARAMETER: A REVIEW ON DISSOLVE OXYGEN (DO) CONTROL METHOD

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Abstract— **Earth consists 71% of water which is an essential element for human survival, precisely on energy sources and daily consumptions A specification has been outlined by World Health Organization (WHO) to determine the water quality parameter (WQP) for each water usage. One of the parameter contained in waste water treatment plant (WWTP) is Dissolve Oxygen (DO). DO is the key parameter in WWTP which determine the suitability of the water usage. DO also helps the biochemistry reaction process wherein the content of DO reflects on the effluent quality and the energy consumption of the wastewater treatment plant. A review on DO control method is presented which highlighted the advantages and disadvantages each of the methods adopted. The objective of this paper is to determine the ideal control method for DO controller.**

Index Terms — **Water Quality Parameter, Dissolve Oxygen, Control, Waste Water Treatment.**

I. INTRODUCTION

Water covers 71% of earth surface and the ocean contains 96.5% of earth water. Human consumes a lot of water in daily usage and the water quality is the subject matter that guarantees the human's life. The water quality parameters are specified by the local authority with certain guidelines based on the water consumption and usage. The specified parameters are turbidity, temperature and pH, color, oxygen demand, water hardness and e-coli content. The most plentiful element on earth is oxygen, and it could be found dissolved in water as O_2 molecules. Oxygen is measured by the dissolved form defined as dissolved oxygen (DO). The dissolved oxygen determines the level of free, presence of non-compound oxygen in water or other liquids. The more oxygen is consumed, the lower of dissolved oxygen level is retained and later creates the disturbance in aquatic ecosystem [1]. In fact, there are many factors that affects the content of DO in water for instance the temperature (climate or season), pressure (altitudes), volume and velocity of water flowing, amount of nutrients in the water and salinity. The oxygen eases to dissolve in colder water, under a great pressure and a low salinity. The number and types of aquatic creatures are commonly determined by the amount dissolved oxygen content [2].

There are several methods that have been implemented in controlling the DO level especially in wastewater treatment plant. Each microorganism (or bug) in plants need at least 0.1 to 0.3 mg/L DO to synthesize food and breed [3]. Most WWTP could maintain about 2 mg/L of DO, hence the existed bugs inside the flocs could retrieve the oxygen [4]. Many studies on DO control methods in wastewater treatment processes have been conducted [5] as such switch control, PID control, gain scheduling control, neural network control, and etc. In this paper, a few control methods that have been implemented to control the DO levels are reviewed. The review of control methods comprises the approach of experimental works, numerical simulations and actual practices. Consequently, the objectives of this paper are to delineate the advantages and disadvantages of DO control methods and determine the ideal choice of control method for DO in optimizing the usage purposes and costs. This paper is organised as follows; a short resume of DO is explained in section 2 followed by the elaboration of DO control methods for wastewater treatment in section 3. Section 4 are discussions on the notion of controller performance and the paper is concluded in section 5.

2.0 DISSOLVED OXYGEN (DO)

Dissolved Oxygen (DO) is formed in oxygen microscopic bubbles that are mixed in the water and existed between the water molecules. DO has been the best indicator in determining the suitability of a water body for aquatic life survival. Water absorbs the oxygen directly from the atmosphere or by aquatic plant and algae photosynthesis whilst the oxygen is removed from the water by respiration and decomposition of organic matter. Plants use aeration tanks to suspend microorganisms in wastewater. Once the primary treatment stage is completed, the sewage is pumped into the aeration tanks. The sludge is loaded with microorganisms and mixed with air or pure oxygen. In the aeration basins, the organic waste is thoroughly mixed and aerated with the help of microorganism activities and presence of forced air. The oxidation process is enhanced with the addition of DO which providing oxygen to aerobic microorganisms in the aeration basin. This process turns the organic wastes into inorganic by products. At this point, the DO content needs to be maintained at 2 mg/L. If the DO is less than 2 mg/L, the microorganisms in the center of the flocs may die since the microorganisms on the outside of the flocs use up the DO first. If the DO content is too low, the environment becomes unstable for these microorganisms and they are prone to die due to the anaerobic conditions. Furthermore, the DO is measured using an electrode and electronic meter or field test kits. However, the use of electronic meter and electrode is inadequate because this method does not measure oxygen directly and the electrode changes the physical behavior of the oxygen in the water. The field test kits (such as a drop bottle, a micro buret, or a digital titrator) involve the addition of a solution of known strength to a treated sample of water from the stream. The amount of solution required to change the color of the sample reflects the concentration of DO in the sample. The amount of oxygen dissolved in water is expressed as a concentration, in milligrams per liter (mg/l) of water.

3.0 CONTROL METHOD

Proportional integral derivative (PID) is often chosen in wastewater treatment control method. PID control is reliable when the control system is well known and the operation situation does not change drastically. The significant nonlinearities are occurred with the presence of uncertainties and disturbances within the system, thus the performance of PID control degrades subsequently. To avoid performance reduction in DO control in wastewater treatment process, various methods are proposed by researchers, including PID auto-tuning [6][7]. There are other linear control methods that have been applied to this control system such as multivariable robust linear control. Model predictive control (MPC), which is widely used in the industries, has been also considered for DO control as in [8]–[11]. Recently, researchers have been devoted in employing artificial intelligence methods for complex nonlinear systems. Adaptive fuzzy control could deal with model uncertainty, and has been applied to DO control in [12]. The capability of neural networks for learning large nonlinearities of the system makes them popular in nonlinear adaptive control, and a back-propagation neural network is used in [13] for DO control. Moreover, integrated method such as neural-fuzzy control [14] and self-organizing radial basis function neural network model predictive control method [15] have been proposed for DO control.

3.1.Proportional Integral Derivative (PID) control

Researchers used feedforward and feedback + PID control schemes based on expert system for DO level control. The different control rules are made with an accordance of the derivative of DO values in different stages. Due to the growing environment of the microbial and energy consumption of the treatment process, some control difficulties could be summarized as follows [4]:

a. Long time delay system that induced by the complexity of biochemical reactions and rapid changing of wastewater quality. This may cause long period from the beginning of aerating to the beginning of DO change in the aeration tank. DO will fluctuates greatly during this period.

b. The great fluctuation causes the aquatic organisms in the tank become unsteady, which affects the activities of the microorganism system.

c. Nonlinear system of aerating process is a high dimensional, strong coupling and high degree. The application of advanced process control algorithm, is very difficult to obtain the accurate numerical model.

d. To guarantee a safe running mode in conventional method, usually the DO set-point value of the system must be settled at high level and consumes much energy.

The control system schematic diagram is shown in Fig.1 which refines the PID control. In order by having good performance in restraining disturbance the expert controllers could implemented for precision and speed of adjusting.

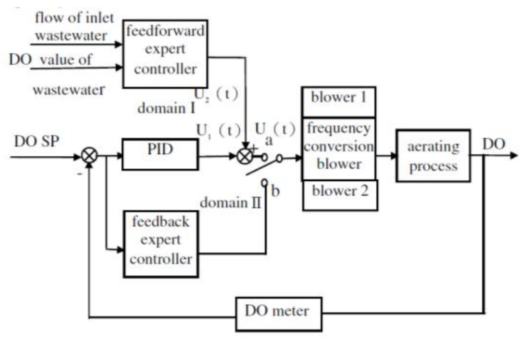


Fig.1 The schematic diagram of control system [4]

PID is the most common control strategy in the process control. It is a continuous feedback loop that keeps the process running normally by taking corrective action whenever there is any deviation from the set point of a process variable. An error occurs when an operator manually changes the set point or when an event or a disturbance changes the load, thus causes a change in the process variable [23]. However, control method proposed by [4] are using feedforward expert with PID to overcome the problem that will maintain the DO value.

3.2. Neural Adaptive control

Mirghasemi et al. [16] proposed an adaptive control method for DO control that provides high performance and robustness to disturbances. The proposed method uses Cerebellar Model Arithmetic Computer (CMAC) neural network with an adaptive neural network approach which has been considered. The CMAC adapts in real time to model nonlinearities. A method of robust weight update is described that avoid the trade-off between performance and stability found with other robust modifications. Previous researchers [10,16,24] used the simulation models as shown in Fig.2 in controlling the DO value.

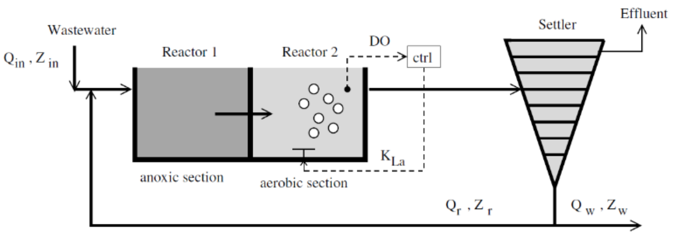


Fig. 2. General overview of simulation model [16]

In the simulation model, only DO concentration is measurable and there is no measurement for any other state variables described in the model. This control strategy utilizes a CMAC to estimate nonlinear behavior of the system.

3.3. Gain Scheduling control

Vald et al. [17] dealt with the robust control of the dissolved oxygen concentration of wastewater treatment processes. Firstly, the dissolved oxygen control loop is experimental identified in various operating points. The Gain Scheduling strategy is designed to monitor the behavior of the closed loop system as it must be identical around the mentioned operating points. This method is successfully applied at different domains and one of the most popular nonlinear control method. This method uses a nonlinear controller with specific required dynamic properties, obtained by combining the members of an invariant linear controller family [18]. Gain Scheduling have the ability to adapt changes in the dynamics of the process controllers. The control scheme with Gain Scheduling controller type is depicted in Fig. 3.

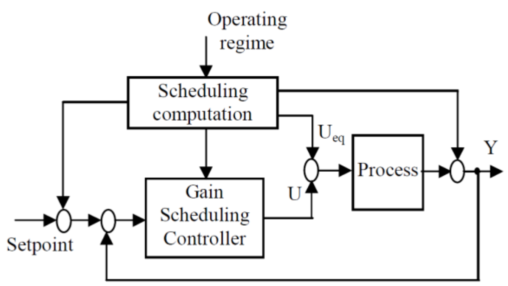


Fig. 3. Control scheme with Gain Scheduling controller type [17]

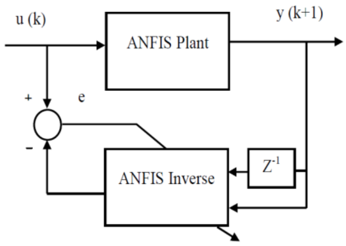
Gain Scheduling robust control method has been chosen, as the evolution of dissolved oxygen concentration is strongly influenced by the evolution of biomass, organic substrate and environmental conditions (temperature, pH etc.).

3.4. Fuzzy control

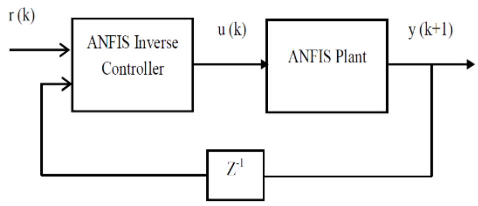
Fuzzy logic is the emulation of human reasoning on computers. Since it is introduced by Zadeh in 1965 [19], it has become popular in various applications. There are various types of fuzzy controllers used to control the DO level. This paper reviews a few control technics that used fuzzy controllers such as ANFIS Inverse Control, Adaptive Fuzzy PID, Nonlinear Fuzzy PI Control and Expert Fuzzy Controller.

3.4.1- Adaptive Neuro Fuzzy Inference System (ANFIS) Inverse Control

Gaya et al. [20] studied an adaptive neuro fuzzy inference system (ANFIS) inverse control of dissolved oxygen in an activated sludge process. To identify, adjust parameters and architecture of the fuzzy inference system (FIS) are used ANFIS learning algorithm [21]. The concept of ANFIS inverse is similar to an open control system [22] witch is straightforward, with feed forward control action. The goals is to maintain the dissolved oxygen concentration within the accepted level and provide a simple and effective control method. There are two stage of inverse learning training for control has done, where the input-output data of the previous ANFIS model is used to obtain the plant inverse ANFIS model as shown in Fig. 4(a); and the implementation stage as in Fig. 4(b). The ANFIS model automatically creates the control action of obtained plant inverse [20].



(a) The ANFIS learning stage



(b) The ANFIS implementation stage

Fig. 4 The schematic diagram of inverse learning training for ANFIS [20]

The controller is quite interesting in terms of simple design model and its capable to handle the complex nonlinearity of dissolved oxygen and simplicity of tuning once a good inverse model is obtained [20].

3.4.2- Adaptive Fuzzy PID Controller

Hong-tao et al. [24] state that adaptive fuzzy PID control has been applied to control the DO concentration because the activated sludge wastewater treatment process is difficult to be controlled due to its complexity, time-varying and non-linear behaviors. The adaptive fuzzy PID controller is an adaptation of controller that used an additional fuzzy logic controller to adjust the parameters of PID controller by fuzzy control rules. The adaptive fuzzy PID controller as stated above is based on two inputs (e and ec) and three outputs (Δkp , Δki , Δkd) .The block diagram of the adaptive fuzzy PID controller of DO is shown in Fig.5. The *e* represents the error and *ec* represents the error change. The *u* is the control law, *y* represents the actual output and *yd* represents the expected output. Δ*kp* ,Δ*ki* and Δ*kd* represents the change of the proportional gain, integral gain and derivative gain, respectively.

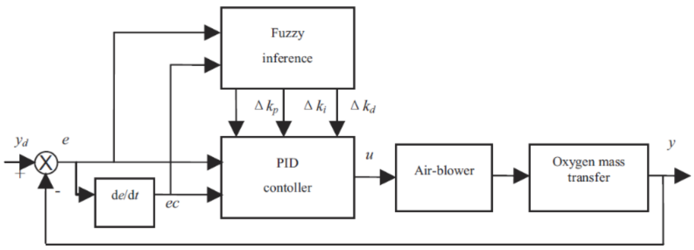


Fig.5. Block diagram of the adaptive fuzzy PID controller of DO [24]

Comparison between PID control and the adaptive fuzzy PID control of DO is made and DO is set to 2 (mg/L). PID control result is shown in Fig.6. Where, the adaptive fuzzy PID control outperforms the PID controller by reducing the oscillating time and shorten the settling time of the system.

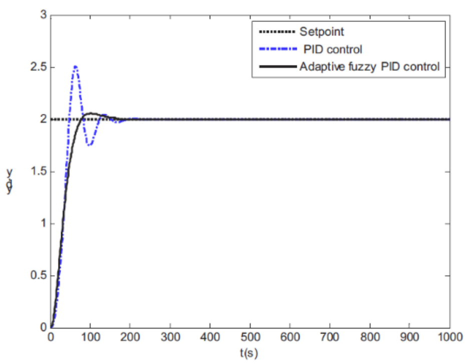


Fig.6. Results of the PID control and adaptive fuzzy PID control [24]

From this study result shows than an effective adaptive fuzzy PID controller may use to solve problem of DO value [24].

3.4.3- Nonlinear Fuzzy PI Control

Zawadzki, and Piotrowski [25] proposed the nonlinear fuzzy PI control system based on Internal Model Control structure. A nonlinear fuzzy PI control system based on Internal Model Control (IMC) [26] is considered in Fig.7. Dynamics aeration system has minor effect on control of DO. Therefore, the inverse of the static aeration systems used for the design of control systems. It is possible only for models of reversible [26]. The DO control error *e*, the reference value of airflow *Qair* ^{ref}, the airflow error *Qair* ^{error} and the airflow value *Qair*^{M} are set by the simplified aeration system model.

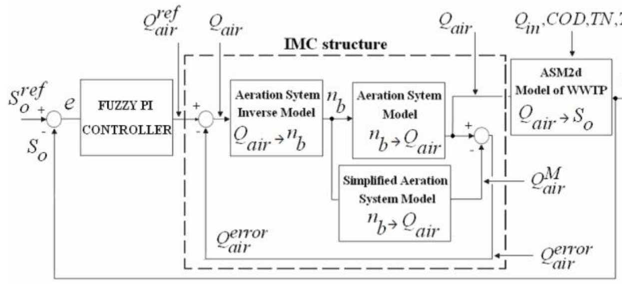


Fig.7. Nonlinear fuzzy control system [25]

A control strategy was tested by simulation based on actual data records from a case study plant. A new approach to detect the concentration of dissolved oxygen including ventilation systems were presented. Nonlinear fuzzy controller has been obtained and tested its performance by simulation. Compared with the control system described in [27], it was found that the method described above (PI control multiregional) has some limitations. We can see that the accuracy of the response satisfactory, but not exceeding the desired value. In addition, the high gain controller results in a short time overshot high values. Moreover, the control system does not respond properly on an increase in noise. As a result, there is a problem retaining DO concentration set point during limited hours [25].

3.4.4- Experts Fuzzy Control System

Yang et al. [28] analyzed the process of cyclic activated sludge technology (CAST) wastewater treatment technology and established a model of dissolved oxygen control. This study emphasizes the sources of instability in the control system step response curve by conventional PID closed-loop system, and provide a method of design experts fuzzy control system. Expert fuzzy control system has a clear advantage in the WWTP [28]. Control methods have some erratic behavior in the sewage treatment process complex biochemical reactions, where DO is related to the time delay. Therefore, the need to create a reference model which has the effect of noise control through predictive control [29] may be necessary. Figure 8, predictive control shown by the expert fuzzy control method of feedback control is used as a predictor.

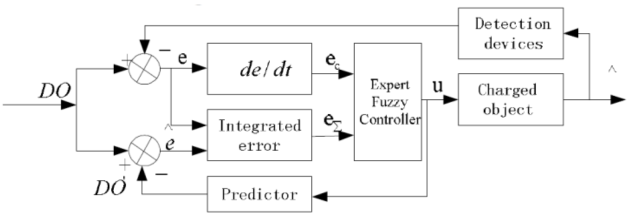


Fig.8. Predictive control based on experts fuzzy control system [28]

The control system has been analyzed separately by graphic simulation has significantly superior performance in a time lag and uncertainty mathematical models. Moreover, [28] provides an effective method for the accurate control system delay in similar condition.

4.0 DISCUSSION

This paper highlights the suitability of control methods in determining and monitoring the DO values that available based on the aforementioned factors that affect the DO content in water body. DO control in WWTP is the most important parameter which improving the wastewater treatment efficiency and energy saving. The constant of DO concentration around 2 mg/L satisfies the need of the growth of bacterium in wastewater [30-32]. Due to the inherent nonlinearity and complexity of DO concentration in wastewater, the conventional control methods like ON/OFF and proportional-integral-derivative (PID) are incompetent methods, whilst intelligent techniques such as the adaptive controllers, the on/off controller with genetic algorithms, the predictive controller, the nonlinear multiregional PI controller, the predictive controller with genetic algorithms, the neural-fuzzy controller, the multivariable PID controller and process identification could give a better control effect [33-36], and could offer an integrating expert knowledge and control rules of the process [37]. In this paper, a review of control methods used to determine the DO values in wastewater treatment plant is presented. The reviewed control methods comprise the approach of experimental works, numerical simulations and actual practices. The control methods that have been reviewed are Proportional Integral Derivative (PID), Neural Adaptive, Gain Scheduling and fuzzy controls. PID controllers are the most common control strategies in the process controls which used feedback loop in corrective actions. PID control generates errors in the PID control if the set point value is changed manually. However, the error is minimized with the use of feedforward expert in PID control. In addition, Neural Adaptive control provides high performance and robustness to disturbances with adoption of CMAC. Gain Scheduling control methods are designed to monitor the behavior of the closed loop system. The Gain Scheduling is one of the controllers that have the ability to adapt changes in the dynamics of the process controllers. However, the Gain Scheduling control method acquires a few steps as such a set of operating point and scheduling for design and implementation. To anticipate, fuzzy controller has been chosen as the most reliable control method in monitoring the DO values. This is because the fuzzy controller is easier to be integrated compared to other control methods such as adaptive neuro fuzzy inference system (ANFIS) inverse control, adaptive fuzzy PID controller, nonlinear fuzzy PI control, experts fuzzy control system and etc. In addition, the fuzzy controller gives an efficient performance in monitoring the DO values and saves more energy.

5.0 CONCLUSION

This paper has review 4 types of DO control method, and there are many other popular types of control method that are not covered, such as model predictive control (MPC) and nonlinear model predictive control (NMPC). Therefore, there is avenue for future research in this area using the above mention control method.

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