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Design and Control Strategy of Diffused Air Aeration System

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Abstract**—**During the past decade, pond aeration systems have been developed which will sustain large quantities of fish and invertebrate biomass. Dissolved Oxygen (DO) is considered to be among the most important water quality parameters in fish culture. Fishponds in aquaculture farms are usually located in remote areas where grid lines are at far distance. Aeration of ponds is required to prevent mortality and to intensify production, especially when feeding is practical, and in warm regions. To increase pond production it is necessary to control dissolved oxygen. Artificial intelligence (AI) techniques are becoming useful as alternate approaches to conventional techniques or as components of integrated systems. They have been used to solve complicated practical problems in various areas and are becoming more and more popular nowadays. This paper presents a new design of diffused aeration system using fuel cell as a power source. Also fuzzy logic control Technique (FLC) is used for controlling the speed of air flow rate from the blower to air piping connected to the pond by adjusting blower speed. MATLAB SIMULINK results show high performance of fuzzy logic control (FLC).

Keywords**—**aeration system, Fuel cell, Artificial intelligence (AI) techniques, fuzzy logic control

I. INTRODUCTION

OXYGEN is the first limiting factor for growth and well-being of fish. Fish require oxygen for respiration, which physiologists express as mg of oxygen consumed per kilogram of fish per hour (mg O^2/kg/h). Aerators are of two basic types: splashers and bubblers. Splasher type splashes water into the air to affect aeration. Splashing action also causes turbulence in the body of water being aerated. Bubbler aerators rely upon release of air bubbles near the bottom of a water body to affect aeration. A large surface area is created between air bubbles and surrounding water. Rising bubbles also create turbulence within a body of water [1, 2]. Circulation of pond water by aerators is an additional benefit of aeration. The study of FLC is the major branch of intelligence control, which is based on the concept of AI. AI can be defined as computer emulation of the human thinking process. During the last ten years, there has been a substantial increase in the interest on artificial neural networks. Specifically, they are good for tasks involving incomplete data sets, fuzzy or incomplete information and for highly complex and ill-defined problems, where humans usually decide on an intuitional basis [3-5]. In this paper a new design and sizing of diffused aeration system is suggested, moreover control of dissolved oxygen of aquaculture system is achieved using FLC technique.

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II. PRINCIPLES OF AERATION

The air contains 20.95% oxygen. At standard barometric pressure (760 mmHg), the pressure or 'tension' of oxygen in air is 159 mmHg. The pressure of oxygen in air drives oxygen into water until the pressure of oxygen in water is equal to the pressure of oxygen in the atmosphere. When pressures of oxygen in water and atmosphere are equal, net movement of oxygen molecules from atmosphere to water ceases. The water is said to be at equilibrium, or at saturation, with dissolved oxygen (DO) when the oxygen pressure in the water equals the pressure of oxygen in the atmosphere. The DO concentration in water at saturation varies with temperature, salinity, and barometric pressure. As water temperature increases, DO concentration at saturation decreases. At a given temperature, the DO concentration at saturation increases in proportion to increasing barometric pressure. The concentration of DO at saturation decreases with increasing salinity. Water also may contain less DO than expected at saturation. At night, respiration by fish, plants, and other pond organisms causes DO concentrations to decline. Thus, during warm months, night-time DO concentrations in ponds often are below saturation. In production ponds, DO may decrease by 5–10 mg/L at night, and in un-aerated ponds, DO concentrations at sunrise may be less than 2 mg/L [6].

III. DIFFUSED AERATION SYSTEM

Diffused-air system aerators use a low pressure, high volume air blower to provide air to diffusers positioned on the pond bottom or suspended in the water. A variety of types of diffusers have been used, including ceramic dome diffusers, porous ceramic tubing, porous paper tubing, perforated rubber tubing, perforated plastic pipe, packed columns. Most diffused-air aerators release a large volume of air at low pressure. The minimum permissible system pressure becomes greater with increasing depth of water above diffusers, because enough pressure must be available to force air through the piping system and cause the air to exit from the diffuser against the hydrostatic pressure at the discharge point.

Diffused-air systems that release fine bubbles usually are more efficient than those that discharge coarse bubbles. This is because fine bubbles present a greater surface area to the surrounding water than larger bubbles. Oxygen diffuses into water at the surface, so a large surface area facilitates greater oxygen absorption. Diffused-air systems also are more efficient in deep ponds than in shallow ponds. Diffused aeration devices are usually classified as either fine or coarse bubble referring to the relative diameter of the bubble produced. Oxygen can be supplied by means of air or pure oxygen bubbles introduced to the water to create additional gas-water interfaces. Submerged bubbles aeration is most frequently accomplished by dispersing air bubbles in the liquid. The diffused or bubble aeration process consists of contacting gas bubbles with water for the purpose of transferring gas to the water. The most commonly used diffuser system consists of a matrix of perforated tubes or membranes or porous plates arranged near the bottom of the pond to provide maximum gas to water contact [7].

IV. PEM Fuel Cell Description

Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy. The basic building block of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on either side [8]. A schematic representation of a fuel cell with the reactant/product gases and the ion conduction flow directions through the cell is shown in Fig. 1. Figure 2 shows the fuel cell power density variation with current density.

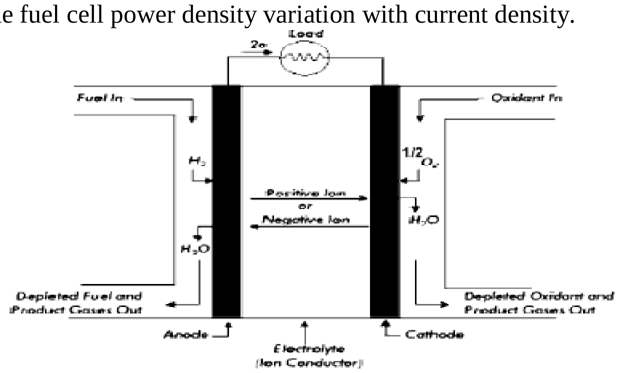

Fig. 1 Schematic of individual fuel cell

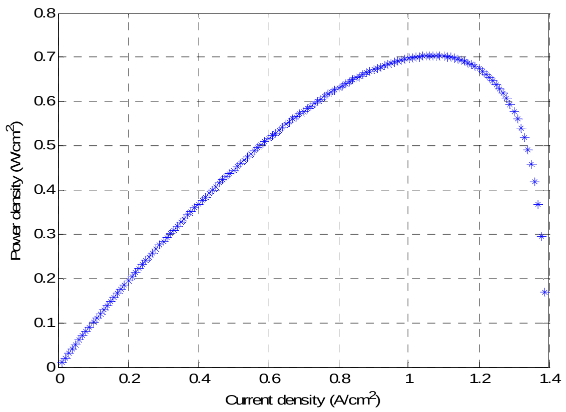

Fig. 2 Fuel cell power density variation with current density

V. Proposed Aeration System

In a submerged aeration system, there are three major components: air supply source, air piping, and the aerator itself. Blowers*;* the air is supplied by the air blower, which is one of two types: rotary positive displacement or centrifugal. Piping*;* the requirement of air and/or liquid piping depends on the type of aerator. All submerged aerators require air piping from which air is transported to the submerged aerator from the onshore air blower. Air Diffuser bubble compressed air into water through orifices, nozzles in air piping, diffuser plates or tubes, or sparges. The proposed system consists of fuel cell stack to provide the system with the required power for operation, controller to control the fuel cell power and blower. Blower feed the system with the required pressure and air flow rate, and finally diffuser connected in the pond bottom as depicted in Fig. 3.

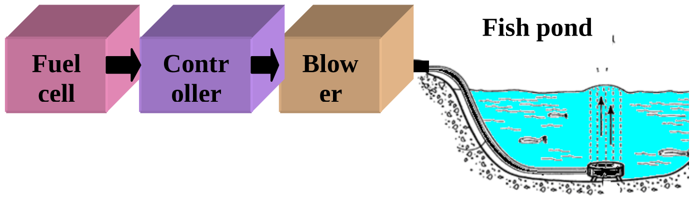

Fig. 3 Block diagram of diffused aeration

VI. Design and Sizing of Diffused Aeration System

Once the oxygen demand is computed, the aeration system can be sized [9].

$$R = OFR \times N \times W \tag{1}$$

Where *OFR* is oxygen/feed ratio (lb/lb), *R* is total ration (lb/d). *W* is weight of animal in grams. Maximum daily oxygen demand (kg/day) can be calculated by

$$DOD = 1.44 \times OFR \times R \tag{2}$$

The blower power can be calculated as:

$$P_b = \frac{1.5\,DOD}{N} \tag{3}$$

Where *DOD* oxygen demand (lb/h), power blower (hp), and *N* is transfer efficiency (lb oxygen/hp per hour). The factor 1.5 is equivalent to assuming that the overall efficiency of the motor and blower is 67% [9].

$$N = N_o \frac{\beta (C_{eff} - C)(1.024)^{(T-20)} \alpha}{C^*_{std}} \tag{4}$$

$$C_{eff} = C^*_{field} (1 + KZ) \tag{5}$$

N is transfer efficiency under field conditions (lb oxygen/hp per hour), N_o is transfer efficiency under standard conditions (lb oxygen/hp per hour), C_{eff} is mean effective dissolved oxygen saturation concentration (mg/1), C_{std} is saturation dissolved oxygen concentration (mg/1) at 20~ barometric pressure 760 mm Hg, T is temperature (^{o}C), *C* is bulk dissolved oxygen concentration in transfer system (mg/l), C_{field}* is saturation value under field conditions (mg/1), *K* is 0.008 for coarse and 0.016 for fine bubble diffusers, and *Z* is depth of diffuser (ft).

The pressures are expressed as follows. The discharge pressure includes the depth of water at the diffuser submergence as well as all the losses in the air piping and diffuser system.

$$P_b = 0.1 G_s \left[\left(\frac{P_d}{P_a} \right)^k - 1 \right] \tag{6}$$

$$N_{diff} = \frac{G_s}{G_{diff}} \tag{7}$$

P_b adiabatic delivered power in kW, G_s airflow rate at standard conditions m_N^3/h, P_d absolute pressure downstream of blower in kPa, P_a absolute pressure upstream of blower kPa [10]

VII. THE PROPOSED CONTROL SYSTEM

The main target of the proposed control system is to adjust the blower air flow rate to feed the aquaculture pond with the required DO percent. FLC control is utilized to provide the system with the required control action as depicted in Fig.4.

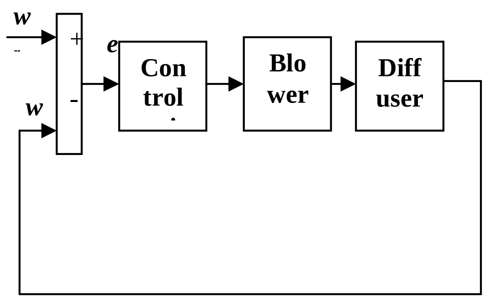

Fig. 4 Block diagram of FLC control for pond dissolved oxygen

VIII. FLC ALGORITHM

Fuzzy logic controller (FLC) techniques have been found to be a good replacement for conventional control techniques, owing to their low computational burden and ease of implementation using microcomputers [11]. The fuzzy-logic based controller overcomes system ambiguities and parameter variations by modeling the control objective based on a human operator experience, common sense, observation and understanding how the system responses, thereby eliminating the need for an explicit mathematical model for the system dynamics[12]. FLC in the last few years, fuzzy logic has met a growing interest in many control applications due to its non-linearity handling features and independence of the plant modeling. FLC operates in a knowledge-based way, and its knowledge relies on a set of linguistic if-then rules, like a human operator.

IX. FLC STRUCTURE

Fuzzy logic systems are widely used for control, system identification, and pattern recognition problems. Fuzzy set theory generalizes classical set theory in that the membership degree of an object to a set is not restricted to the integers 0 and 1, but may take on any value in [0,1]. By elaborating on the notion of fuzzy sets and fuzzy relations we can define fuzzy logic systems (FLS). FLSs are rule-based systems in which an input is first *fuzzified* (i.e., converted from a crisp number to a fuzzy set) and subsequently processed by an inference engine that retrieves knowledge in the form of fuzzy rules contained in a rule-base. The fuzzy sets computed by the fuzzy inference as the output of each rule are then composed and *defuzzified* (i.e., converted from a fuzzy set to a crisp number). A fuzzy logic system is a nonlinear mapping from the input to the output space. A schematic representation of a FLS is presented in Fig. 5. The operation of a FLS is based on the rules contained in the rule base [11-13].

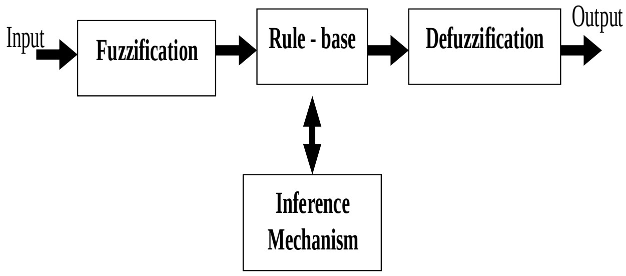

Fig. 5 Fuzzy controller architecture

A. Fuzzy logic controller benefits

In many control applications, the model of the system is unknown or the input parameters are highly variable and unstable. In such cases, fuzzy controllers can be applied. These are more robust and cheaper than conventional PID controllers. It is also easier to understand and modify fuzzy controller rules, which not only use human operator's strategy but, are expressed in natural linguistic terms. Fuzzy controller can implement design objectives, difficult to express mathematically in linguistic or descriptive rules.

X. PROPOSED CONTROL SYSTEM

Fuzzy logic control offers a way of dealing with modeling problems by implementing linguistic. Table 1 shows possible control rule base which are used. The rows represent the rate of the error change (ce) and the columns represent the error (e). Each pair (e, ce) determines the output level from NL to PL corresponding to output. Here NL is negative big, NM is negative medium, NS is negative small, Z is zero, PS is positive small, PM is positive medium and PL is positive big. The corresponding membership functions are depicted in Fig. 6. The continuity of input membership functions, reasoning method, and defuzzification method for the continuity of the mapping u_{fuzzy} (e, $e^{\cdot}$) are necessary. In this paper, the triangular membership function, the max-min reasoning method, and the center of gravity defuzzification method are used. Figure 7 shows the MATLAB SIMULINK of FLC system.

TABLE I
RULE BASE OF FUZZY LOGIC CONTROLLER

ce e	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NS	NS	**ZE**
NM	NL	NL	NL	NM	NS	ZE	**PS**
NS	NL	NL	NL	NS	ZE	PS	**PS**
Z	NL	NM	NS	ZE	PS	PM	**PL**
PS	NS	NS	ZE	PS	PL	PL	**PL**
PM	NS	ZE	PS	PM	PL	PL	**PL**
PL	**ZE**	**PS**	**PS**	**PL**	**PL**	**PL**	**PL**

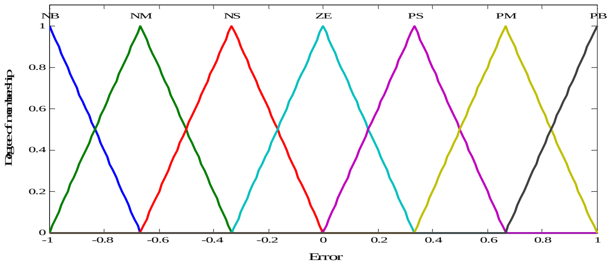

Fig. 6 Membership functions

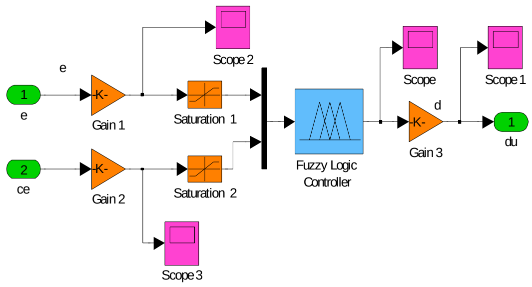

Fig. 7 AFLC architecture

XI. MATLAB SIMULATION RESULTS

The simulation model of the proposed electrical system of diffused aeration system using FLC control technique is depicted in Fig. 8, the system consists of fuel cell subsystem, control subsystem for fuel cell to control mass flow rate of fuel cell input gases, blower subsystem, and finally control subsystem for motor. The block digram of DO SIMULINK is depicted in Fig. 9.

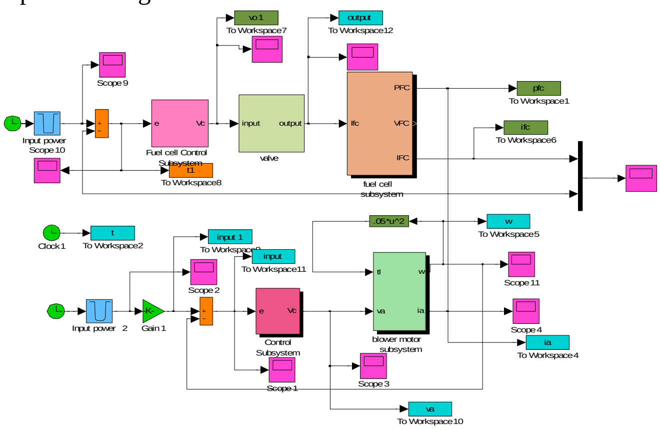

Fig. 8 Electrical system of diffused aeration system using FLC control

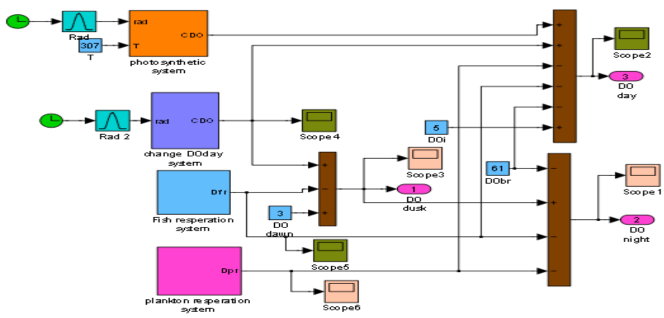

Fig. 9 Block diagram of dissolved oxygen model

XII. RESULTS AND DISCUSSION

The sizing of the aeration system is calculated by determine the required dissolved oxygen over the day, and so the required power of the blower and finally calculate the required air flow rate. The system under consideration requires 40 diffuser of ceramic disc with flow rate of 4 m_N^3/h, and the blower power equal 823.4 W. The layout of diffusers in an aquaculture pond has an important influence on the performance of the system. Pond geometry, diffuser submergence, diffuser density and placement of the diffusers all must be considered in system design. Full floor grids arrangement is used; Full floor grid arrangements are defined as any total floor coverage by diffusers. Air piping laterals are most often constructed of PVC material. Figure 10 shows DO found in the pond over the day and DO percentage required by diffused aeration system. It is clear that DO require in night hours are larger than day hours because of the photosynthesis process is presented in the day hours only.The results of the MATLAB SIMULINK show a good performance of control subsystem. Figure 11 indicates the blower speed variation with time, it is clear that during night DO is very low so the blower speed is high to adjust the required amount of DO in water, during the day hours the blower speed is low due to high DO percent.Figure 12 presents the error signal; the error signal is very small and approximately equal zero.The FLC system success in tracking the target very well as shown in Fig. 13 the blower speed track reference signal very well.Figure 15 represents the required DO added using diffused air aeration system with that calculated during the day, it is clear that the diffused air aeration is able to generate the desired amount of DO, and the FLC has the ability to adjust blower speed very well.

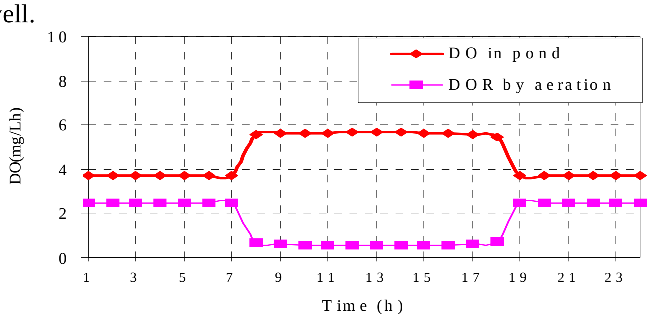

Fig. 10 Dissolved oxygen concentration

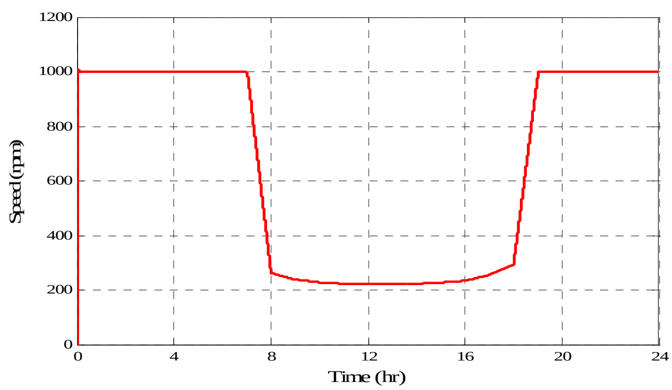

Fig. 11 Motor speed variation over the day

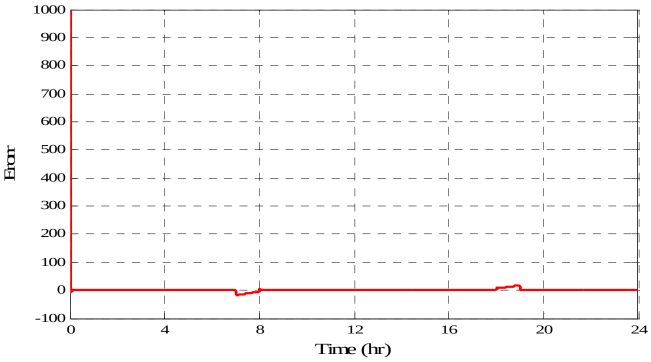

Fig. 12 The error signal

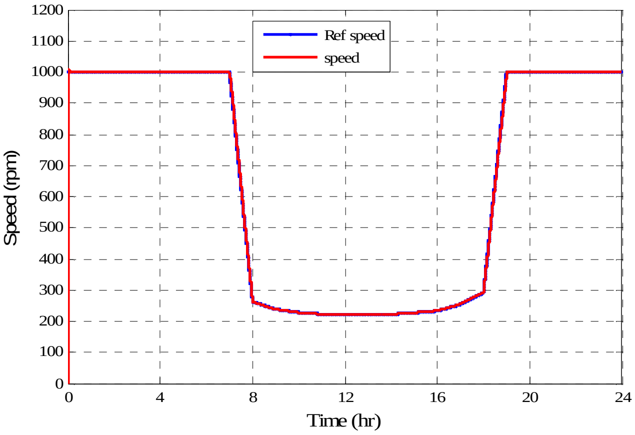

Fig. 13 Blower speed variation with reference signal

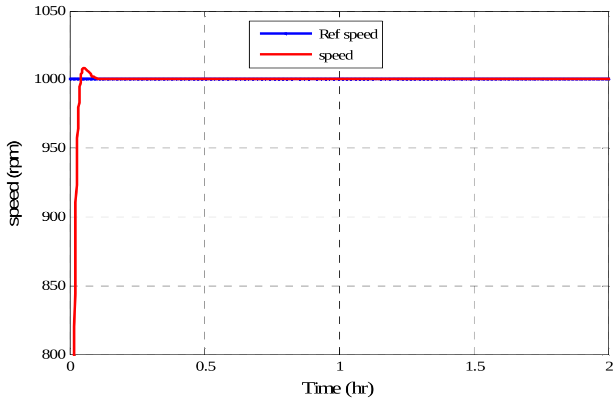

Fig. 14 Blower speed response at sudden variation

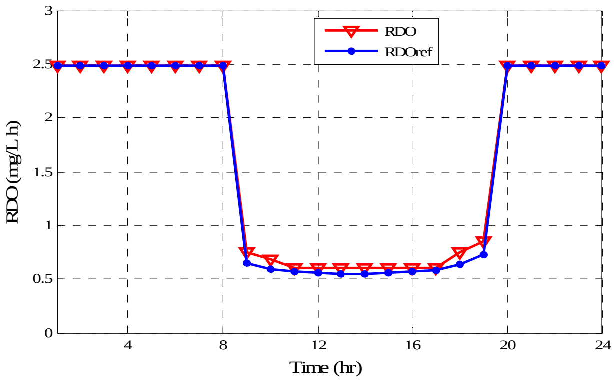

Fig. 15 Comparison between dissolved oxygen obtained from simulation and required value during the day

XIII. Conclusion

The goal of most fish farmers is to maximize production and profits while holding labor and management efforts to the minimum. In most pond culture operations, aeration offers the most immediate and practical solution to water quality problems encountered at higher stocking and feeding rates. Aeration means addition of oxygen to the water. This process is accomplished either by exposing the water to air or by introducing air into the water. In this paper a new design and sizing of dissolved air aeration system for aquaculture pond is suggested and control of dissolved oxygen of aquaculture system is achieved using FLC technique. The results show the high performance of control subsystem.

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