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The Improvement of Flexible Aerator Parameter to Increase Dissolved Oxygen Level in Freshwater

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Abstract: Dissolved oxygen is an important requirement for aquatic life. The aerator machine is able to increase the amount of dissolved oxygen in water. A paddle wheel is a widely used aerator machine. A new type of aerator, flexible link aerator, has been introduced to increase the quality of dissolved oxygen in water. To improve the dissolved oxygen level, suitable parameters of flexible link are determined by using MATLAB & Simulink. The width of the flexible link is adjusted from *0.036m* to *0.050m* while its length is kept constant at *0.55m* and *0.65*m in two different simulations using MATLAB & Simulink. In terms of dissolved oxygen results, the estimator level displays a constant and stable result for all the combinations of lengths and widths used. In comparison with *0.55m,* the *0.65m* length of flexible link shows a better result. Based on the simulation results shown, a width of *0.047m* and a length of *0.65m* present the best parameters for the flexible link manipulator.

Keywords: Flexible Link, Aerator, Dissolved Oxygen, Width, Length

1. Introduction

The improvement of environment agriculture industry is significant for the development of agricultural product. An increase in the demand for quality products by the consumer leads to the growth of agriculture industry. Many factors need to be taken into account to improve the quality of product while increasing quantity. In the agriculture industry, important requirements to improve the quality of water are the pH value, the amount of dissolved oxygen and the concentration of water. The quality of water can change with a change in water temperature and atmosphere. An increase in dissolved oxygen levels in water results in a temperature decrease. This happens due to the weather effect and the elevation of nature [1]. Increasing the amount of dissolved oxygen can improve the quality of water for aquatic life but increasing other elements, such as ammonia level, can lead to fish interruption or death [2].

Dissolved oxygen concentration is influenced by many different aspects. These include photosynthesis rate, water temperature, the degree of light penetration, wave action or water turbulence, the decay of organic matter and the amount of respiration of oxygen [3]. The viscosity, transparency, total dissolved oxygen and conductivity can be affected, either directly or indirectly, by dissolved oxygen and pH in water [4]. Dissolved oxygen is maintained at the surface by diffusion from the atmosphere and photosynthesis but at the bottom of the pond, the dissolved oxygen percentage can be increased by mixing wind and wave action [5]. The dissolved oxygen concentration is an important irrigation water quality parameter that can become a limiting factor for some intensive agriculture systems [6]. Water contamination is frequently associated with agricultural activities and they are used to measure the physicochemical and biological parameters like iron, pH, electrical conductivity and the amount of dissolved oxygen to monitor the quality of water [7].

The aeration system has been widely used to generate dissolved oxygen in ponds and to increase the quality of water in paddle wheel [8,9]. Aeration is important for providing suitable dissolved oxygen levels for aquatic living as well as keeping the biomass suspension [10]. One of the methods for controlling the aeration system is by manipulating

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parameters like wavelength. For injection or diffused aeration, the variable that needs to be controlled is the valve position, or pressure, while for mechanical or surface aeration, power input of the machine is that variable.

The improvement in aerator machine can help improve the productivity of aquatic life and control thermal stratification of water. The control approach by Arduino system is able to maintain the quality of water based on dissolved oxygen level in the aerator machines [11]. The flexible link aerator creates a similar function to that of the paddle wheel, which is to improve the quality of dissolved oxygen by using the flexible link for covering the area of water. Flexible link manipulator, however, has a higher payload-to-robot weight ratio, lower manufacturing cost, lower power consumption and is easier to transport because of its lighter weight. That's why they are widely used in the industry [12].

Flexible link aerator is also used to increase and maintain the dissolved oxygen level in water. The greatest advantage of flexible link manipulator is its ability to improve the performance system by using elastic characteristics compared to the rigid link manipulator. The lighter weight of link manipulator also improves system performance by reducing power consumption which makes the operation further easier [13]. Based on mechanical aerator function, the plate touches the surface of water while moving in a horizontal motion as shown in Figure 1. The type of material is important according to the function of operation. Generally, stainless steel is deemed suitable to use for the lightweight, high-strength and high-speed moving operations. The measurement for single link flexible manipulator is a combination between the higher moving speed and the payload [15].

Fig. 1 - Flexible Link Aerator [14]

The development of controller system for flexible link manipulator involves constructing a mathematical model. The mathematical equation of motion is a bit complicated due to the flexibility characteristics [16]. The flexible link manipulator consists of two elements; the rigid degree of freedom and the elastic degree of freedom. To construct the mathematical model, the flexible link manipulator's equation requires the nonlinear differential equation arising from material characteristics which are caused by the dynamic behaviour. An accurate mathematical model is difficult to construct using conventional technique because of the system being nonlinear. Computer simulations are able to track the reference trajectory for a nonlinear model, described by the dynamic behaviour for a closed-loop control approach, to improve the oscillation motion of the flexible link manipulator [17].

This paper deals with simulations of flexible link aerator for single link manipulator. Simulations are performed using MATLAB & Simulink. The dissolved oxygen estimator level results are determined by adjusting the angular displacement and acceleration.

2. Methodology

The main objective of this paper is to determine the suitable parameters for the flexible link manipulator as shown in the workflow diagram in Figure 2 below. The mathematical model for flexible link can be develop using finite difference method. Since the flexible link are implemented into the water, it needs to use a suitable boundary condition. Due to the addition of circular hole in the design require the irregular boundaries. The boundary condition had been determined as shown in equation (1).

$$EI\frac{\partial^2 u(l,t)}{\partial x^2} = 0 \quad (1)$$

A boundary condition in equation (1) are based on the assumption:

- The displacement at $hub\ (x,t)$ must be zero
- Total applied torque must be the same force at the hub after water resistance in included.
- Mass, M_p at the end point is equal to the shear force.
- The end point should not have external force and stress at the end point is zero.

In order to solve the Partial Differential Equation (PDE) in equation (1), the Finite Difference (FD) method will be used as shown in equation (2).

$$\frac{\partial^3 u(x,t)}{\partial t^2 \partial x} = \frac{u_{i,j+1} - 2u_{i,j} + u_{i,j-1} - u_{i-1,j+1} + 2u_{i-1,j} - u_{i-1,j-1}}{\Delta x \Delta t^2}$$
$$\frac{\partial^3 u(x,t)}{\partial x^2 \partial t} = \frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j} + u_{i+1,j-1} - 2u_{i,j-1} - u_{i-1,j-1}}{\Delta t \Delta x^2} \quad (2)$$

The modified boundary condition are based on the governing equation as shown in equation (3).

$$EI\frac{\partial^4 u(x,t)}{\partial x^4} + \rho\frac{\partial^2 u(x,t)}{\delta t^2} = -\rho x\ddot{\theta} \quad (3)$$

The new boundary condition is shown in equation (4).

$$u(0,t) = 0$$
$$I_h\frac{\partial^3 u(0,t)}{\partial t^4 \partial x} + EI\frac{\partial^2 u(0,t)}{\delta x^2} = \tau(t) - F_{d\ new}(t)L$$
$$M_p\frac{\partial^3 u(l,t)}{\partial t^2} - EI\frac{\partial^2 u(l,t)}{\delta x^3} = 0$$
$$EI\frac{\partial^2 u(l,t)}{\delta x^3} = 0 \quad (4)$$

$Where$

$F_{d\ new} = 0.5\rho v^2 C_d A_{new}$

$A_{new} = Area\ of\ plate - Total\ area\ of\ circular\ holes$

The finite difference method (FD) equation suitable to the irregular boundary conditions by using Taylor series expansion. Substitute of FD equation into governing equation (3) will yield equation (5).

$$u_{i,j+1} = -x\ddot{\theta}(t)(\beta\Delta t)^2 + au_{i,j} + b\left(u_{i+1,j} + u_{i-1,j}\right) - c\left(u_{i+2,j} + u_{i-2,j}\right) - u_{i,j-1} \quad (5)$$

$Where$

$$a = 2 - \frac{9EI(\beta\Delta t)^2}{2\rho(\alpha\Delta x)^4};\ b = \frac{3EI(\beta\Delta t)^2}{\rho(\alpha\Delta x)^4};\ c = \frac{3EI(\beta\Delta t)^2}{4\rho(\alpha\Delta x)^4}$$

Substitute FD equation into equation (5) yield the boundary condition $u_{1,j+1}$ at the hub.

$$u_{1,j+1} = K_1 u_{1,j} + K_2 u_{2,j} + K_3 u_{3,j} + K_4 u_{1,j-1} + K_5 x\ddot{\theta}(t) + K_6(\tau(t) - F_{d\ new}) \quad (6)$$

$Where$

$$K_1 = 2 - \frac{9EI(\beta\Delta t)^2}{2\rho(\alpha\Delta x)^4};\ K_2 = \frac{bEI(\beta\Delta t)^2}{EI(\beta\Delta x)^2 - cI_h\alpha\Delta x}$$
$$K_3 = -\frac{cEI(\beta\Delta t)^2}{EI(\beta\Delta t)^2 - cI_h\alpha\Delta x};\ K_4 = -1$$
$$K_5 = -\frac{EI(\beta\Delta t)^2}{EI(\beta\Delta t)^2 - cI_h\alpha\Delta x};\ K_6 = -\frac{c(\alpha\Delta x)^2(\beta\Delta t)^2}{EI(\beta\Delta t)^2 - cI_h\alpha\Delta x}$$

The boundary displacement u_{n-1} and u_n at the end point and simplifying the equation (7) and (8).

$$u_{n-1,j+1} = -K_7 x\ddot{\theta}(t) + K_8 u_{n,j} + K_9 u_{n-1,j} + K_{10} u_{n-2,j} + K_{11} u_{n-3,j} + K_{12} u_{n-1,j-1} \quad (7)$$

and

$$u_{n,j+1} = K_{13} x\ddot{\theta}(t) + K_{14} u_{n,j} + K_{15} u_{n-1,j} + K_{16} u_{n-2,j} + K_{17} u_{n,j-1} \quad (8)$$

where the value of K is.

$K_7 = -(\beta\Delta t)^2 \,; K_8 = (b - 2c)\,; K_9 = (a + c)\,; K_{10} = b$

$K_{11} = -c\,; K_{12} = -1\,; K_{13} = -(\beta\Delta t)^2 \,; K_{14} = a + 2b - 4c$

$K_{15} = -2c\,; K_{16} = 2c\,; K_{17} = -1$

Convert into matrix formulation as shown in equation (9).

$$U_{i,j+1} = AU_{i,j} + BU_{i,j-1} + CF \tag{9}$$

$$U_{i,j+1} = \begin{bmatrix} u_{1,j+1} \\ u_{2,j+1} \\ \vdots \\ u_{n,j+1} \end{bmatrix} \quad U_{i,j} = \begin{bmatrix} u_{1,j} \\ u_{2,j} \\ \vdots \\ u_{n,j} \end{bmatrix} \quad U_{i,j-1} = \begin{bmatrix} u_{1,j-1} \\ u_{2,j-1} \\ \vdots \\ u_{n,j-1} \end{bmatrix} \tag{10}$$

$$A = \begin{bmatrix} K_1 & K_2 & K_3 & 0 & 0 & \cdots & 0 & 0 \\ -c & b & a & 0 & 0 & \cdots & 0 & 0 \\ b & -c & b & b & b & \cdots & 0 & 0 \\ \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\ 0 & 0 & \cdots & -c & b & a & b & -c \\ 0 & 0 & \cdots & 0 & K_8 & K_9 & K_{10} & K_{11} \\ 0 & 0 & \cdots & 0 & K_{14} & K_{15} & K_{16} & K_{17} \end{bmatrix} \tag{11}$$

$$B = \begin{bmatrix} K_4 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & \cdots & 0 & 0 \\ \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\ 0 & 0 & \cdots & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 & 0 & K_{12} & 0 \\ 0 & 0 & \cdots & 0 & 0 & 0 & 0 & K_{18} \end{bmatrix} \tag{12}$$

$$C = \begin{bmatrix} x\ddot{\theta}(t) & (\tau(t) - F_{d\,new}) & 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\ 0 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 & 0 & x\ddot{\theta}(t) & 0 \\ 0 & 0 & \cdots & 0 & 0 & 0 & 0 & x\ddot{\theta}(t) \end{bmatrix} \tag{13}$$

$$F = [\,K_5 \;\; K_6 \;\; \cdots \;\; \cdots \;\; K_7 \;\; K_{13}\,] \tag{14}$$

A mathematical model has been implemented and converted to block diagram to get the information about the width and length of the flexible link. Block diagrams were constructed based on the theoretical information to simulate the flexible link aerator by using MATLAB & Simulink. The result is obtained from the best simulation analysis by adjusting the parameters based on the output result in MATLAB & Simulink.

The simulation is utilized with a mathematical model to simulate the dynamic equation of a flexible link. The parameters required for running the simulation include torque and the flexible plate material. Simulation of discrete-time linear systems requires the notation for the equations shown in (15) and (16) [18] [19].

$$\begin{gathered} x(n+1) = Px(n) + Qu \\ y(n) = Rx(n) + Su \end{gathered} \tag{15}$$

where

$$P = \begin{bmatrix} A & \vdots & B \\ \cdots & \cdots & \cdots \\ I_{N\times N} & \vdots & 0_{N\times N} \end{bmatrix} ; Q = \begin{bmatrix} C \\ \cdots \\ 0_{N\times 1} \end{bmatrix} ; R = [I_N \quad 0_N]\,; S = [0_{2N}] \tag{16}$$

$$F = [K_6\; 0 \cdots 0\,]^T\,, \qquad u = [\tau\; 0 \cdots 0\,]^T$$

$$y(n) = [x(1,n) \cdots x(N,n), x(1,n-1) \cdots x(N,n-1)]$$

& N = Number of sections

Input of a simulation is used through state space model to represent the overall flexible link system.

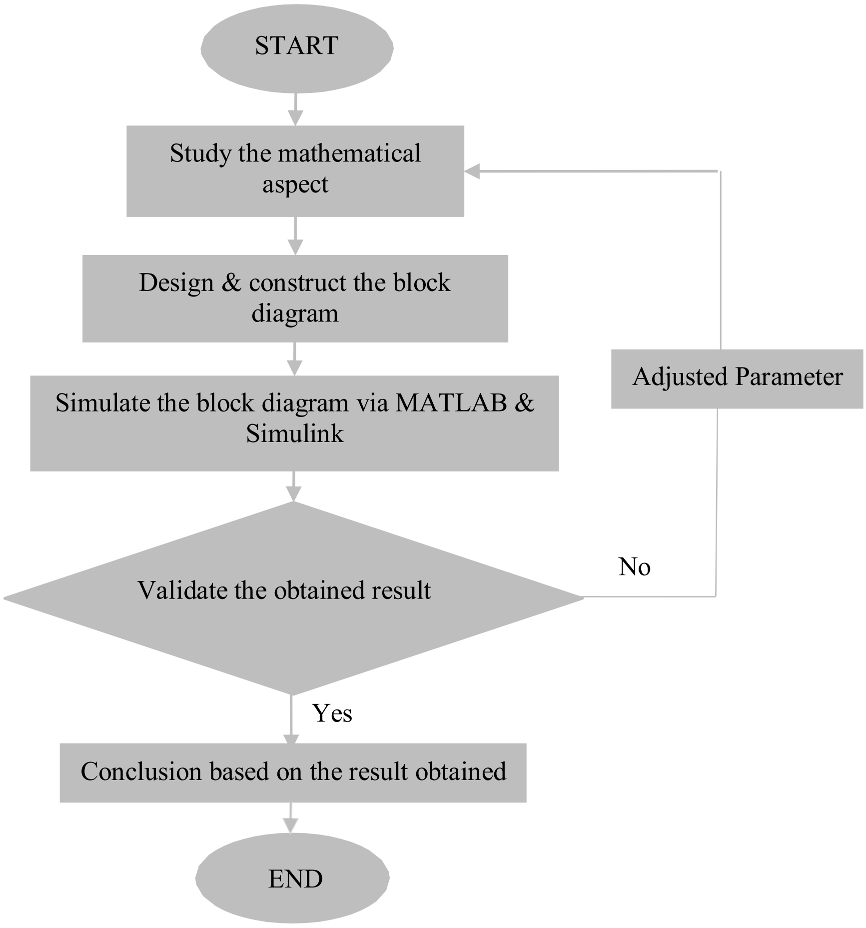

Fig. 2 – Workflow Diagram

The flexible link aerator analysis is simulated by using torque as an input, and the position of the flexible beam deflection as an output. The input system requires the input voltage, motor torque and the drag force with water resistance state as constant. The result shown in angular displacement is represented as dissolved oxygen estimator. The dissolved oxygen estimator consists of the speed of movement and length of the flexible link in water.

The length and width were selected by considering the applying ability torque toward motor drive. The motor torque had been stated as 3.5 Nm, with the mass load depending on the length of flexible link including the additional loads existing from water drag force. Different lengths of the flexible link are tried until the system reaches an unstable state in the simulation of the flexible link. Meanwhile, the width of flexible link is adjusted between 0.036m and 0.050m.

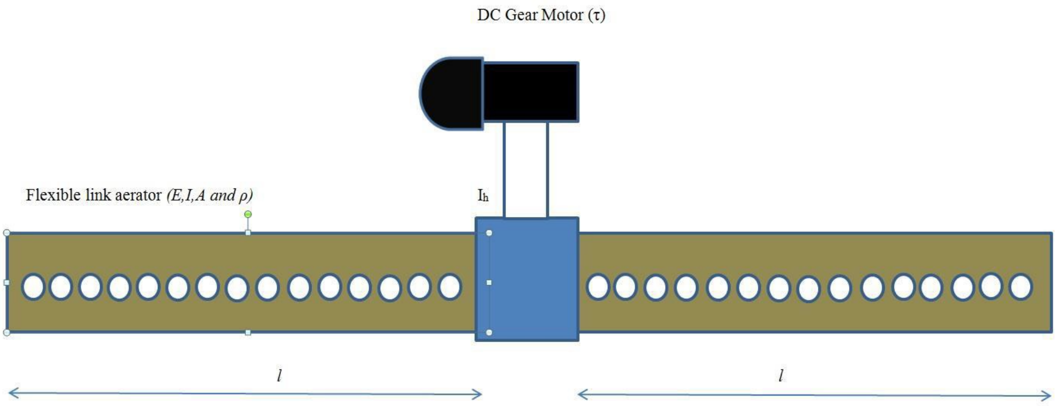

Fig. 3 - Outline of the flexible aerator with embedded holes [13]

3. Results

Various widths and lengths were simulated to propose the most suitable parameters for operating the aerator. After iterations and trial and error on several flexible link widths and lengths, the suitable parameters were determined. The parameters (width and length) were selected by considering the ability to apply torque towards the motor drive. The motor torque was stated as 3Nm, the mass load depending on the flexible link's parameters. Length of the flexible link is 0.55m and 0.65m while the width was adjusted between 0.036m and 0.050m. According to the simulation of width of flexible link 0.050m are the maximum movement, it can reach above the 0.050m width of flexible link there no oscillation is produced to represent the dissolved oxygen generated. When both the length and width are increased, the deflection at the end point increases with the water drag force and burdens the drive motor.

3.1 Simulation of 0.65 m length of single link manipulator with adjusted width from 0.036 m to 0.050 m

The simulation results in Figure 4 below demonstrate the estimator level of dissolved oxygen for the flexible link manipulator length of 0.65m while the width is changed from 0.036m to 0.050m.

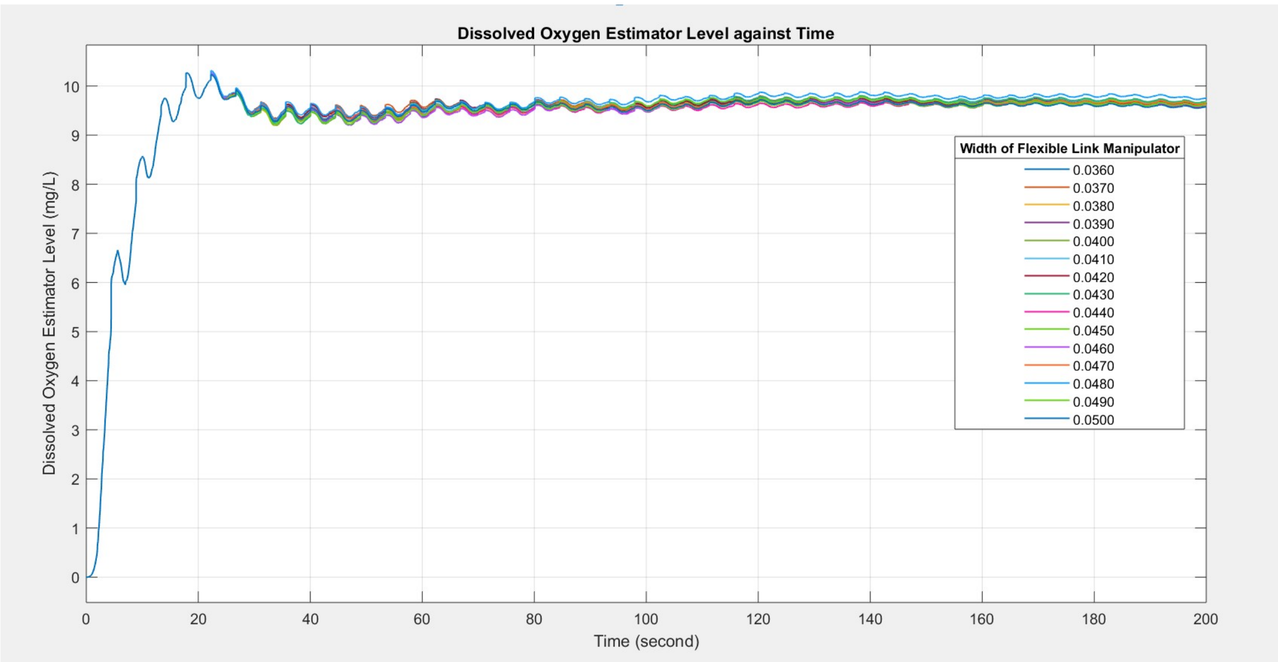

Fig. 4 - Estimated dissolved oxygen level from 0.036m to 0.050m width of the flexible link at 0.65m length

Figure 4 shown that the simulation results of dissolved oxygen estimator level of the flexible link are constant and stable for the parameters of 0.036 m to 0.050 m width of flexible link at 0.65 m length. While in Table 1 and 2 shows a specific value had been achieve the estimator of dissolved oxygen level using 0.65m length of flexible link manipulator while adjusted the width value from 0.036m to 0.050m.

Table 1 - Table of measurement width of flexible link manipulator from 0.036m to 0.050m at 0.65m length for dissolved oxygen estimator level

Width (m)	Dissolved oxygen estimator level (mg/L)
0.036	9.665
0.037	9.666
0.038	9.679
0.039	9.628
0.040	9.685
0.041	9.649
0.042	9.685
0.043	9.599

Table 2 - Table of measurement width of flexible link manipulator from 0.036m to 0.050m at 0.65m length for dissolved oxygen estimator level (cont.)

Width (m)	Dissolved oxygen estimator level (mg/L)
0.044	9.663
0.045	9.613
0.046	9.648
0.047	9.758
0.048	9.621
0.049	9.580
0.050	9.645

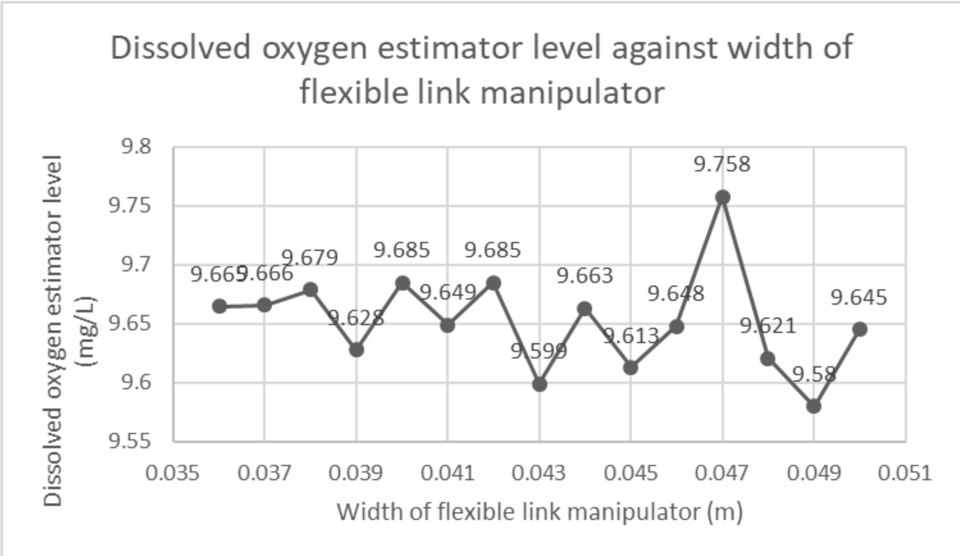

Fig. 5 - Graph of dissolve oxygen level against width of flexible link between 0.036m to 0.050m for 0.65m length of flexible link manipulator

According to graph shown in Figure 5, the minimum value of dissolved oxygen level is 9.588 mg/L are achieved at 0.049m of width of flexible link manipulator and the maximum dissolved oxygen level is 9.731 mg/L at 0.047m of width of flexible link manipulator for 0.65m length of flexible link.

3.2 Simulation of 0.55 m length of single link manipulator with adjusted width from 0.036 m to 0.050 m

The width parameter of the flexible link is adjusted from 0.036m to 0.050m for a flexible link manipulator length of 0.55m now. The simulation results in Figure 6 demonstrate the estimator level of dissolved oxygen for 0.001m width changes. For the length 0.55m of flexible link manipulator in the increasing width of flexible link at 0.036m to 0.050m show a constant result based on simulation result of dissolved oxygen estimator level of flexible link as shown in Figure 6. Based on Table 3 the specific value of dissolved oxygen estimator level a shown and the graph of dissolved oxygen estimator level against width of flexible link manipulator as shown in Figure 7. For the 0.55m length of the flexible link, simulation shows that the minimum value of the dissolved oxygen level is 8.639 mg/L at 0.043m width of flexible link manipulator and its maximum value is 8.753 mg/L at 0.047m width of flexible link manipulator. Based on the simulation results, the dissolved oxygen estimator level presents a stable result as the width was increased from 0.036m to 0.050m.

Comparing with the simulations obtained at 0.65m length of the flexible link, the dissolved oxygen level is lower than 0.55m which is 8mg/L dissolved oxygen value at 0.55m and 9mg/L at 0.65m length of flexible link manipulator. According to the simulation in Figure 4 and Figure 6 it shows that the dissolved oxygen generated between 0.036m to 0.050m of width flexible link were acceptable to use for flexible link aerator machine. The maximum dissolved oxygen level generated for 0.65m length of flexible link are 9.731mg/L during 0.047m width of flexible link while 8.753mg/L dissolved oxygen level generated at 0.55m length and 0.047m width of flexible link. The optimum parameter of flexible link aerator for generated higher dissolved oxygen were with 0.65m length and 0.047m width of flexible link.

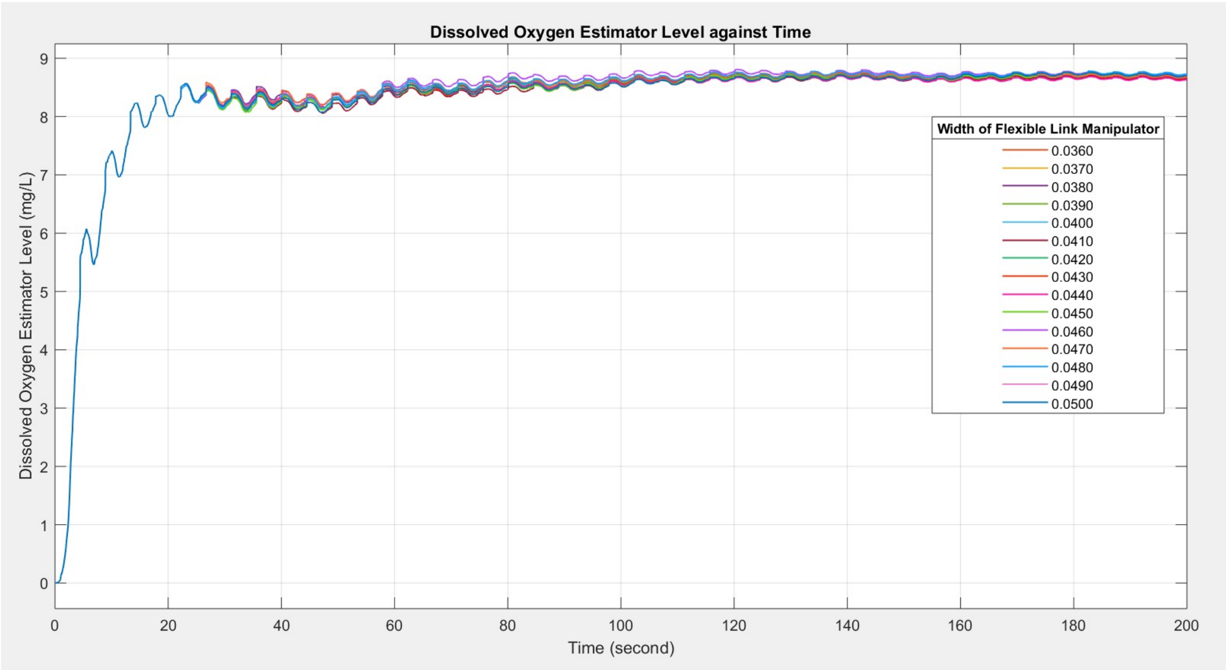

Fig. 6 - Estimated dissolved oxygen level toward 0.036m to 0.050m width of flexible link at 0.55m length

Table 3 - Table of measurement width of flexible link manipulator from 0.036m to 0.050m at 0.55m length for dissolved oxygen estimator level

Width (m)	Dissolved oxygen estimator level (mg/L)
0.036	8.677
0.037	8.671
0.038	8.676
0.039	8.680
0.040	8.654
0.041	8.694
0.042	8.673
0.043	8.632
0.044	8.706
0.045	8.718
0.046	8.681
0.047	8.733
0.048	8.689
0.049	8.703
0.050	8.685

Table 4 - Comparison Dissolved Oxygen Level for Flexible link Aerator

Voltage (V)	Length of Flexible Link (m)	Immerse % in water	Dissolved Oxygen Level (mg/L)						
			Simulation Result (Shah, 2012)	% Error	Simulation Result PVC (Zulkipli, 2015)	% Error	Simulation Result Aluminium (Zulkipli, 2015)	% Error	Simulation Result Aluminium (Anuar, 2019)
12	0.55	25	7.457	16.48	8.634	0.60	8.674	0.14	8.686
12	0.65	25	9.065	6.60	9.650	0.13	9.607	0.58	9.663

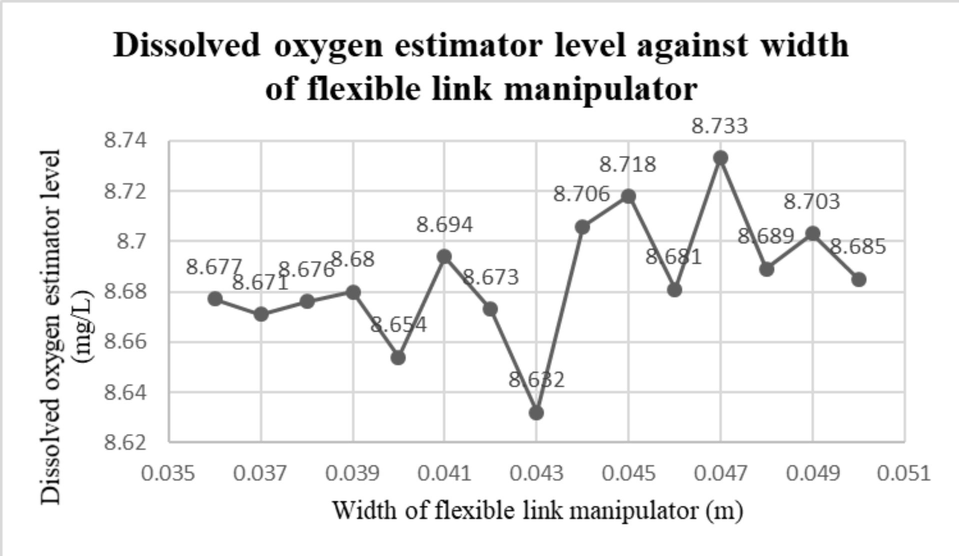

Fig. 7 - Graph of dissolve oxygen level against width of flexible link between 0.036m to 0.050m for 0.55m length of flexible link manipulator

3.3 Comparison Dissolved Oxygen Level for Flexible Link Aerator

The comparison of dissolved oxygen generated using flexible link based of different length between 0.55m and 0.65m are shown in Table 4. These simulations show the dissolved oxygen level generated were above the critical level 4mg/L. It shows that these parameters were acceptable to use for the flexible link aerator machine in actual experiment. However, the parameter that had a higher dissolved oxygen level generated was selected due to its utmost performance. For 0.55m length of flexible link manipulator the percentage error between simulation result of Aluminium flexible link manipulator with holes and adjusted width from Anuar, 2019 and the simulation result of solid plate of flexible link manipulator from Shah, 2012 is 16.48%. The percentage error between simulation result of Aluminium flexible link manipulator with holes and adjusted width from Anuar, 2019 and the simulation result of PVC flexible link manipulator with holes and constant width from Zulkipli, 2015 is 0.60% while 0.14% of percentage error form simulation result of Aluminium flexible link manipulator with holes and constant width from Zulkipli, 2015.

For 0.65m length of flexible link manipulator the percentage error for simulation result of Aluminium flexible link manipulator with holes and adjusted width from Anuar. 2019 with simulation result of solid plate of flexible link manipulator from Shah, 2012, simulation result of PVC flexible link manipulator with holes and constant width from Zulkipli, 2015 and simulation result of Aluminium flexible link manipulator with holes and constant width is 6.60%, 0.13% and 0.58% respectively. According to the result 12V of voltage are used with 25% immerse level while the flexible link of width 0.047m was selected as the optimum parameter for flexible link aerator.

4. Conclusion

The conclusion of this simulation is that the dissolved oxygen estimator level shows a constant and stable result for both lengths of the flexible link, 0.65m and 0.55m. Comparing the two, the dissolved oxygen estimator level at 0.65m is higher than that at 0.55m. The average result for both shows that, with the 0.65m length in the lead with 9.663 mg/L, and the 0.55m length trailing at 8.686 mg/L. Hence, the best overall result occurs at 0.65m length and 0.047m width of the flexible link manipulator.

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