Novelty of Mechanical Surface Aerator Using Flexible Beam to Generate Dissolved Oxygen in Water

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Abstract

This paper presents the result of experiment the flexible beam aerator model as a new concept to generate dissolved oxygen. This flexible beam method is inverted as compared to other researches done in this field. The vibration generated from the movement of the flexible beam will generate waves and bubbles in water thus generating dissolved oxygen. In this experiment, by using a optimum parameter setup, this new concept aerator able to generated dissolved oxygen up to 8.6 mg/L with the average Standard Oxygen Transfer Efficiency 1.84 kgO₂/kWh. The key factor in developing this method is by implement the characteristic of this flexible beam where it length can cover more surface water area. More water surface area expose to atmosphere it will encourage oxygen to absorb in water. The flexible beam movements circulate the water thus the dissolved oxygen can distribute from top to bottom. Three type experiments were done to find out the optimum parameter setting for this aerator. The best setting will give a higher dissolved oxygen level.

Keyword: Flexible Beam, Dissolved Oxygen, Aerator.

Introduction

Oxygen is critical to the survival of aquatic plants and animals, and a shortage of dissolved oxygen is not only a sign of pollution, it is harmful to the fish. The dissolved oxygen comes from many sources, but the largest source of oxygen is absorbed from the atmosphere [1], [2]. Wave action and splashing allows more oxygen to be absorbed into the water. A second major source of oxygen is aquatic plants, including algae; during photosynthesis plants remove carbon dioxide from the water and replace it with oxygen.

Oxygen is continuously moving between the water and the surrounding air. The direction and speed of this movement is dependent upon the amount of contact between the air and water. The more of the water’s surface is exposed to the air; it will absorb more oxygen from the atmosphere than a calm, smooth body of water [3]. This is the idea behind aerators; by creating bubbles and waves the surface area is increased and more oxygen can enter the water.

Flexible Link

Flexible link is one of the important parts in robotic manipulator research study. This is because flexible link has advantages lower cost due to weight of material used, larger work volume, higher operational speed, greater payload-to-manipulator weight ratio, smaller actuators, lower energy consumption, better maneuverability, better transportability and safer operation due to reduced inertia [4].

By using a control algorithm, the elastic deformations of the endpoint of the link can be controlled and the vibration of the flexible link can also be controlled. In sequence, the vibration produced from
the flexible link give more benefit for this new aerator such it has the potential to create waves and bubbles in the water. Thus, it can be manipulated to generate dissolved oxygen in water.

The new boundary condition for the mathematical model for this flexible link system is proposed. Because of the interaction and contact between a solid body and a fluid, either liquid or gas occurs, and one is moving will yield a drag force. It is a force caused by a fluid such as water, air or any liquid and gas impinging upon an object or otherwise [5]. The drag force is a function of the fluid velocity and density along with the object's reference area and drag coefficient. Different shape will indicate a different of drag coefficient and it also can be varied.

**The aerator**

Good aerator must capable directly adds oxygen to water (oxygenates) and ensure the dissolved oxygen uniformly throughout the pond, circulated and mixes of water top to bottom. This important aspect when a facing with a bottom dwelling animal which cannot come to the surface. It also must capable to moves aerated water away from the immediate area around the aerator, so that it not retreating the same water while dragging in un-aerated water.

![Figure 1: Common type of aerator concept](image)

Various types of aerator systems have been developed over the years as an effort to improve energy efficiency of oxygen mass transfer process and to maintain the desired level of dissolved oxygen in wastewater. As shown in Figure 1, there are three common types of aerator method can categories [6]. Most efficient concept is surface mechanical aeration method, which increase interfacial area by spraying water droplet into the air. The others concept is diffuser aeration method, which release bubble beneath surface of water and combine and turbine aeration method, which introduced larger air bubble into the water and reduce their sizes mechanically.

One of the famous surface mechanical aerator widely use is paddlewheel. This aerator offers a better efficiency and convenience operation and maintenance. Boyd, C.E in his report as in Table 1. clearly shown the mechanical aeration method; paddlewheel is more efficient compare the other aerator method [7].

<table>
<thead>
<tr>
<th>Type of aerator</th>
<th>Average Oxygen Transfer Efficiency (kgO₂/kWhr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddlewheel</td>
<td>2.13</td>
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<tr>
<td>Propeller aspirator pump</td>
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</tr>
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<tr>
<td>Diffused air</td>
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</tr>
</tbody>
</table>

Table 1: Standard Oxygen Transfer Efficiency of Basic Type of Aerator (Boyd, C.E, 1990).
New aerator concept

To implement the flexible beam as an aerator in water, there are two possible ways can be practice. Move in vertical or horizontal way. The best way is by design the flexible beam move with horizontal movement as shown in Figure 2. By using this concept the flexible beam will attaches to hub motor and it move left and right frequently at the surface layer of water. This concept is practical because it will create more contact with water’s surface area continuously. Moreover, this allows the aerator to covering more ponds’ surface area. The longest flexible beam used, more area can be covered and more dissolved oxygen will be generated and as the result it enhance water circulation. However it depends on the capability of the motor to hold the load. The longest flexible beam use, it will cause more load to handle due to resistance of water during the movement and also from flexible’s weight.

Figure 2: Illustration concept of movement

One of the important parts in this aerator machine is the motor as a driver for the overall system. It will generate the movement of flexible beam to produce dissolved oxygen level in water. The factor need to consider in order to select the motor are low power consumption, easy to maintenance, can operate in longer time and have good durability. Motor with 12 Volts and 4 ampere was selected, where the maximum torque up to 3.2 Nm. The angle for movement of flexible beam is designed at 90 degree measured from end to end side. This angle selected by considers the design of the gear and the capability of the motor to operate efficiently. Figure 3 shows the block diagram of the system.

Figure 3: Block diagram of the system

The fabrication of actual model had been done by consideration of all the aspect and following the preferred concept. This aerator model will fitted by the motor to drive the movement of flexible beam in water. To design the aerator, material selection and water resistance to the motor must be consider. Material used must capability resistance from rust, strong from cracking and can handle the vibration. Figure 4 shows the basic model of flexible beam aerator, where it will be test and prove this new concept aerator idea.
Experimental Setup

Experiment was prepared by assemble the Aluminum beam with thickness 2 mm and length 0.45 meter. Aerator is placed at the middle of the reservoir properly without any swag at the aerator holder as in Figure 6. It will be tested in water reservoir with length and width is 3.0 X 3.0 meter with the depth about 0.7 meters. Power supply 12V is used and it is connected to the aerator. Moreover, the reservoir is filled with clean freshwater and measure the level of water contact to the level of flexible beam. It need measure with three different level of water, which is flexible beam immersing in water in 15%, 25%, 50% and 60%.

By using the dissolved oxygen meter, the initial dissolved oxygen level in water can measured and record. Switch ON the aerator and monitor and record the level every 10 minutes until the level become saturated. By controlling the voltage of the motor, it will affect to the speed of the flexible beam movement and will affect to the vibration and deflection of the beam.

After the dissolved oxygen reaches to the saturated level, the aerator’s power needs to switch OFF and let the dissolved oxygen in water to release. Then the experiment repeated by using 9V and 6V. Precede the experiment by change length of beam 0.55 and 0.65 meter. Lastly, repeat the experiment with different level of water in reservoir so that the flexible beam immersing in water in 15%, 50% and 60% from its width. At every experiment setup, it will show the best dissolved oxygen reading, where the dissolved oxygen reading is at higher level. Use the best setup for subsequent experiment.
Results

Table 1: Result of dissolved oxygen level

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Flexible beam length</th>
<th>Immerse in water</th>
<th>Average reading Dissolved Oxygen Level mg/L</th>
</tr>
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<tbody>
<tr>
<td>12V</td>
<td>0.55m</td>
<td>25%</td>
<td>7.4</td>
</tr>
<tr>
<td>9V</td>
<td>0.55m</td>
<td>25%</td>
<td>6.4</td>
</tr>
<tr>
<td>6V</td>
<td>0.55m</td>
<td>25%</td>
<td>5.5</td>
</tr>
<tr>
<td>12V</td>
<td>0.45m</td>
<td>25%</td>
<td>6.9</td>
</tr>
<tr>
<td>12V</td>
<td>0.55m</td>
<td>25%</td>
<td>7.4</td>
</tr>
<tr>
<td>12V</td>
<td>0.65m</td>
<td>25%</td>
<td>8.6</td>
</tr>
<tr>
<td>12V</td>
<td>0.65m</td>
<td>15%</td>
<td>8.6</td>
</tr>
<tr>
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<td>8.6</td>
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<td>12V</td>
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</tr>
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From the Table 1, the immerse level for the aerator run optimum are between 15 to 50 percent, where at this range, the dissolved oxygen can generated up to at 8.6 mg/L. It need to combine with the optimum length of flexible beam where the selected length was 0.65 m. By using this setting for length parameter, it produces better dissolved oxygen result compare the shortest length either in actual experiment or simulation. The voltage use by the motor related to the aerator’s driver motor speed. When the voltages apply is lower, the motor will run with slow movement. Then it was resulting less dissolved oxygen in water. The reason is when the flexible beam that contact with water move slowly, it cannot create big wave to circulating the water to around the reservoir. Thus less water surface area will expose to atmosphere and less of distributed dissolved oxygen between top to bottom water.

The important outcome of this research is to identify Standard Oxygen Transfer Rate (SOTR) for the designed flexible beam aerator. It very important to obtain the time responds by the system whether it can be perform well or not. SOTR can be calculating by using equations shown below [6];

\[
SOTR = (K_{L,a20})(C_{s20})(V)(10^{-3}) \text{ kgO}_2/\text{hr}
\]

Where;

\[
K_{L,a20} = K_{L,aT} \div 1.024^{T-20} \quad \text{is The Oxygen Transfer Coefficient At 20}\degree\text{C and T is water temperature (}\degree\text{C)}
\]

\[
C_{s20} = \text{Dissolved oxygen (DO) concentration at saturation, 20}\degree\text{C (mg/L)}
\]

\[
V = \text{water volume in m}^3
\]

The calculated optimum standard oxygen rate transfer of this flexible beam aerator is 1.84 kg O\(_2\) /Hr as shown in Table 2. It presents an efficiency of common basic type aerator. As a new aerator concept, this aerator was performed well where it oxygen transfer rate efficiency quite steady to compare to other type aerator. This performance result was predicted as mention the mechanical aerator is better than other type of aerator. Result of this standard oxygen rate transfer in this research also supported by the characteristic of flexible beam itself where flexible beam normally use very less power to maneuver. Thus it use less of power and this effecting to standard oxygen rate transfer calculation.
Table 2: Standard Oxygen Transfer Efficiency of Basic Type of Aerator

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**Conclusion**

This new concept aerator proves that flexible link is able to use as aerator to generate dissolved oxygen. In this research show, this aerator able to generated dissolved oxygen up to 8.6 mg/L with the average Oxygen Transfer Efficiency value 1.84 kgO₂/kWhr as shown in Table 2. It achieve by using the optimum value of setup, where it use the full voltage 12V to run the aerator at full speed with the longest length of beam can be support, 0.65 meter and suitable level to immerse the flexible beam in water between 15 to 50 percent from it width. The key of successes implement the flexible beam as an aerator because advantages from it design where it can create more water surface area contact to air and provide good water circulation due to beam length used. Thus, oxygen easy get through to water when the water expose more to atmosphere.

**Recommendation**

The material of flexible beam can be change by using other material that have better Young’s Modulus, and less density. This will give more advantage to allow this aerator to use longer length of flexible link and decrease the motor driver burden. Attaching a floating at the end point of flexible beam, it will decrease a gravity load by the motor, thus the motor can move with less burden, and it might be can support for the motor to use longest length of flexible beam By doing this, significantly it will increase the dissolved oxygen level and covering more water surface area.

**Acknowledgments**

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**References**


[4] Mansour T, Konno A and Uchiyama M.(2010), Vibration Based Control for Flexible Link Manipulator, Tohoku University,

