FLEXIBLE LINK AERATOR FOR DISSOLVED OXYGEN GENERATION IN TIGER PRAWN POND

MUHAMMAD AMIR BIN MAT SHAH

A project report submitted in partial
fulfillment of the requirement for the award of the
Master's Degree of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

AUGUST 2014

ABSTRACT

In the aquaculture industry, the dissolved oxygen is one of the important parameters that need to be monitored seriously. Aerator is normally used to increase the level of dissolved oxygen in water. It functions to circulate or mixes the water top to bottom to ensure that the oxygen content is uniform throughout the pond. It also exposes the water surface to absorb oxygen from atmosphere. This aerator uses a new concept by using flexible link to generate dissolved oxygen. The advantages that have in flexible link were used as an actuator to generate and distribute dissolved oxygen in water. Three type experiments were done to find out and verified the optimum parameter setting for this aerator. The best result of dissolved oxygen level were found during run the flexible link aerator at full power with 0.65m length of flexible link and immerses 25% in water. As a result, the flexible link was successfully implemented as a new aerator concept where it is able to generate oxygen up to 8.6mg/L with the average Standard Oxygen Transfer Efficiency 1.84 $kgO_2/kWhr$ and suitable to used in the shallow pond. The key success factor in developing this method is due to the characteristics that are available on flexible link where it length can be extended to cover the surface of the water without burdening the motor. More water surface area exposed to the atmosphere it will encourage the absorption oxygen into water.

ABSTRAK

Dalam industri akuakultur, oksigen terlarut adalah salah satu parameter penting yang perlu dipantau dengan serius. Mesin pengudaraan biasanya digunakan untuk meningkatkan tahap oksigen terlarut di dalam air. Ia berfungsi untuk mengedarkan atau mencampurkan oksigen terlarut dari permukaan hingga ke bawah dan memastikan bahawa kandungan oksigen terlarut adalah seragam kolam. Ia juga berfungsi mendedahkan permukaan air ke atmosfera supaya oksigen dapat diserap ke dalam air. Mesin pengudaraan dalam kajian ini mempamirkan satu konsep pengudaraan baru dengan menggunakan kepingan fleksibel untuk menjana oksigen terlarut. Kelebihan yang ada pada kepingan fleksibel ini telah digunakan sebagai penggerak untuk menjana dan mengedarkan oksigen terlarut di dalam air. Tiga eksperimen jenis telah dijalankan untuk mengenalpasti dan mengesahkan parameter yang optimum. Ujikaji yang telah dijalankan adalah ujian kelajuan mesin pengudaraan, panjang kepingan fleksibel dan tahap rendam yang berbeza di dalam air. Bacaan oksigen terlarut yang terbaik didapati ketika menjalankan mesin pengudaraan ini dengan menggunakan kuasa penuh, berserta panjang kepingan fleksibel 0.65m dan tahap rendaman 25% di dalam air. Hasilnya mesin pengudaraan ini mampu menjana oksigen terlarut sehingga 8.6mg/L dengan purata Kecekapan Piawai 1.84 kgO_2/kWj dan ianya sesuai digunakan pada kolam yang cetek. Faktor utama kejayaan dalam membangunkan kaedah ini adalah disebabkan oleh ciri-ciri yang terdapat pada kepingan fleksibel ini yang mana ia tidak membebankan motor walaupun menggunakan kepingan fleksibel yang lebih panjang. Lebih luas permukaan air terdedah kepada udara ia akan menggalakkan penyerapan oksigen kedalam air.

CONTENTS

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULT AND DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATION

SAE	-	Standard Aerator Efficiency
SDTR	-	Standard Oxygen Transfer Rate
N/A	-	Not Available
kgO_2	-	Kilo gram oxygen
kW	-	Kilo Watts
kWh	-	Kilo Watts hour
V	-	Voltage
$\frac{d(m)}{dt}$	-	Mass transfer rate
D_m	-	Coefficient of the gas in square centimeters per second (cm^2/sec)
A	-	Area
$\frac{d(C)}{dt}$	-	Concentration gradient of the gas
mg/l	-	Milli gram per liter
τ	-	Torque
E	-	Young's modulus
I	-	second moment of inertia
ρ	-	Density
l	-	Length
δ	-	Deflection
θ(t)	-	Radian angle
PDE	-	Partial Differential Equation
M_p	-	Mass at end point

F_d	-	Drag force
C_d	-	Drag force coefficient
ν	-	Velocity
DC	-	Direct current
Nm	-	Newton Meter
m	-	Meter
ω	-	Angular velocity
b	-	Width
d	-	Thickness
%	-	Percentage
D.O	-	Dissolved Oxygen
^oC	-	Temperature in Celcius
i	-	Current
K_La_{20}	-	The Oxygen Transfer Coefficient At 20^oC
C_{s20}	-	Dissolved oxygen (DO) concentration at saturation, 20^oC (mg/L)
V	-	water volume in m^3
C_m	-	Measured DO concentration
rad/s^2	-	Angular acceleration in Radian per second square
a.m	-	*Ante meridiem* mean before midday
p.m	-	*Post meridiem* mean after midday
Hr	-	Hours
C_{ss}	-	Saturated dissolved Oxygen
A	-	Ampere

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

This research is about the new aerator concept that is suitable for shallow pond which can perform as well as common aerator. The concept that was used by this aerator has not been practice yet. It will overcome the limitation of popular mechanical aerator, which is the paddlewheel. Paddlewheel is not suitable to use in shallow pond, where the downward water force movement can disturb the bottom of the pond and make the pond muddy. Meanwhile, other aerators such as diffuser type aerators are inefficient as compared to paddlewheel because it consumes more power to operate.

Dissolved oxygen level increases as wider water surface were exposed to the atmosphere. By implementing the mechanical contact along the water surface, it will increase the area of water exposed to the atmosphere and simultaneously increase the absorption of oxygen. Currently, only the paddlewheel use this concept. However, it has some limitation as mentioned above.

The new concept used by this flexible link aerator is by moving the flexible link as an actuator that contact with the water surface without creating downward force inside the pond. It was achieved by designing an aerator that have a long plate at the hub and driven at horizontal axis using high torque motor. High torque motor are preferable compared to high speed motor, because it has the capability to handle more load such as water drag force and actuator weight.

Flexible link aerators were chosen based on length to weight ratio factor. It is commonly used to improve the speed of operation and handling larger payloads compared to rigid link aerators. Longer plate allows the aerator to cover wider water surface area to generate dissolved oxygen and circulate the water. As mention by Vidoni et al. (2013) in their research, the heaviness of flexible link will decrease speed and the system required more energy to operate. The demand for better performances and higher speed make it necessary to consider lightweight manipulators because they required less energy to move and have more maneuverability. At the same time, the weight will not burden the driver motor and can increase the speed of movement of the aerator. These characteristics could lengthen the durability and lifetime of the driver motor.

The existing mathematical model of flexible link had been synchronized with the new boundary condition, where the flexible link now implements at water surface. The finite different method was used to develop mathematical model for flexible link aerator. The mathematical model was then simulated using Matlab SIMULINK. Observation was made on the effects of deflection behavior of flexible link aerators towards the level of estimated dissolved oxygen. Simultaneously from this simulation, the optimum parameters were defined such as the length of flexible link aerator plate, voltage to control motor speed, and the percentage of immerse flexible link in water.

All parameters obtained from the simulation were used on actual model which were designed and fabricated. The actual model were used on clean water reservoir to find out the level of dissolved oxygen generated and the efficiency were calculated and compared to other types of aerator.

1.2 Problem Statement

Oxygen is the most important element to sustain our life. Animals and human being cannot survive without oxygen. Carbon dioxide exhale from animals and human being were used by plants for photosynthesis which will produce oxygen. Lack of oxygen will disrupt this life cycle will disrupt and could cause fatality to living creatures. Oxygen is not only important for respiration, but also to destroy harmful bacteria in human and animal body without affecting the beneficial bacteria.

Bugbee and Blonquist (2006) stated that, about 20.95% oxygen can be found in the atmosphere. Oxygen can also be found in water molecule. Aquatic animals require oxygen in water to survive just like land animals. Oxygen in water is called dissolved oxygen. Even though oxygen can be found in water molecule, these aquatic lives are unable to separate the oxygen gases. Due to that, they require pure oxygen gases. Shortage of dissolved oxygen indicates existence of pollution and can be harmful to the aquatic animals.

In aquaculture industry, dissolved oxygen is one of the major parameters need to be monitored seriously. Aerator is normally used to increase the level of dissolved oxygen in water. The function is to circulate or mix the water from top to bottom to ensure that the oxygen content is uniform within the entire pond. Aerator also helps to expose the water surface to absorb more oxygen from the atmosphere.

Paddlewheel is one of the most popular aerator machines to generate dissolve oxygen. The latest improvement of existing adjustable impeller is water breaking impeller, designed for power saving and high aeration. It contributes to lower power consumption due to the professional water breaking and parabolic design. However, it is not suitable to use in shallow pond. Due to the rotation force of water that created from the movement of the paddlewheel, the bottom of pond is disturbed and causes the pond to become muddy.

Shallow pond is required for bottom dwelling animals and animals that are difficult to move to the surface such as tiger prawn. Because of the constraint of financial resources and to minimize the operating cost, the pond designed was exceeding the depth that required. This is to suit the paddlewheel circumstances. To ensure the dissolved oxygen circulate and arrive to the bottom of the pond, paddlewheel need to operate more than it should to prevent the shortage of dissolved oxygen.

1.3 Objectives

A study proposed in this research is to developing a new concept of aerator using flexible link to generate dissolved oxygen. The specific objectives of this study are carried out are described below:

i. To investigate new concept of aerator with lower initial and operating cost with better performance compared to existing aerator.
ii. To develop model with finite different simulation algorithm of the flexible link aerator
iii. To test and evaluate the performance of actual model.

1.4 Importance of the Study

This research is important to encourage the tiger prawn agriculture industry as the aquaculture industry in Malaysia and give opportunity to choose a suitable mechanical aerator. Level of dissolved oxygen is one of the most influential factors to be considered in term of the technical aspect in aquaculture farming. It will determine the quality of water. Water quality plays an important role in hatchery, farming and distributing activity especially in intensive farming. However, cost in operating the aerator become the burden and reduce the profit. Thus, aerator with lower operating cost, easy to maintain and good durability is highly recommended. Basically, it combines several engineering disciplines such as engineering control, material science and fluid engineering to handle a problem in design and control system in those activities.

Significant of this research will develop a new technology and concept of aerator in aquaculture engineering. In this research the movement of flexible link is implements in water to become an aerator and there is no aerator concept yet as in this research. Thus, it will add more option of aerator especially the mechanical aerator type in the aquaculture engineering. This research also develops a new knowledge. The mathematical model development by using the finite different method can be use as a reference in future to any related research especially to conduct the flexible link experiment in different boundary conditions.

1.5 Scope of Study

Scope of study in this research is within the limited range of the engineering field area. It limited to find suitable design concept which is suitable to use in shallow pond such as tiger prawn pond. The concept of aerator movement was implementation from the flexible link movement. The flexible link aerator model developed using the existing mathematical model with water boundary condition. The mathematical model was developed using partial differential equation and was then transfer into a block model in Matlab SIMULINK.

The simulation model is limited to find the optimum parameters and to observe the end point angular overshoot effect to the estimated dissolved oxygen level. The optimum parameters that need to be clarified in this research are the voltage used which it related to the speed of the movement, the suitable length, and the percentage immerse of flexible link in water. These parameters are important because it will affect the amount of dissolved oxygen generated.

In this research, the simulation model is important for future research, where it can be altered or modified to be used in other related experiment. Dissolved oxygen level can be estimated without consuming time and money on fabricating new aerator machine for the experiment. Since current flexible link aerator machine uses only basic aerator design, a lot of part can be upgraded in future as cited in the recommendation section later in this thesis.

Later, actual aerator model is fabricated for the experiment. Then the experimental results compared with simulation results to verify the optimal parameters of aerator. The final step is to calculate and compare the flexible link aerator efficiency with other aerators.

1.6 Flowchart of research

There are 4 phases had been through to perform this research. Figure 1.1 shows a brief phase of research that encountered in this research. It starts with finding a suitable design concept and translated into engineering design drawings. The next phase was simulating the developed mathematical model of flexible link in boundary condition of water. The simulation result were use to prepare the actual flexible link. Actual flexible link aerator machine then fabricated according to the drawing concept made in the first phase. Experimental have been conducted to verify the simulation result. Finally, the parameters used by the flexible link aerator have been analysed and aerator efficiency was calculated to compare its performance with other aeration.

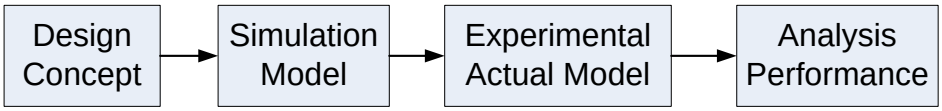


Figure 1.1 : Research Phases

1.7 Organisation of the thesis

A brief outline of the contents of the rest of the thesis is given below:

Chapter 2 present a literature review about the prawn farming, how aerators work in producing the dissolved oxygen in the pond. The next literature review is regarding the advantages of flexible links and some relevant research that have been made. These important topics are very necessary to understand in order to facilitate proper aerator machine design that meets the needs to breeding tiger prawns. Literature review on the effectiveness of the other aerator machine is also made as a benchmark so that the flexible link aerators designed can achieve a good level.

Chapter 3 present the methodology and the process of developing a mathematical model of a flexible link aerator. It starts with making the design concept. Then developed the existing flexible link mathematical model by considering water as the new boundary conditions. It followed by simulated using MATLAB SIMULINK. This chapter also describes the procedures for using the dissolved oxygen meter and way to conduct an experiment for actual flexible link. It also shows the formula that used to calculate the efficiency of aerator.

Chapter 4 present the results of simulation and experimental results. It started by do a simulation of an appropriate length of flexible links that do not burden the aerator motor There are three types of simulations and experiments have been done which is running an aerator at different speeds by control the input voltage by operate ventilators by different lengths of flexible links and operate an aerator by sink the flexible link at a different level. At the end of this chapter, it shown the flexible link aerator efficiency compared to other aerator.

Chapter 5 present the conclusion on the objectives that has been achieved. Some of recommendations for future work also mentioned in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The structure of the literature review for this research is consists of four main topics; there are introduction to tiger prawns characteristics, dissolved oxygen generated, how aeration functioning and about the flexible link. These topics are important to get more information about the background of the research and to achieve the objectives. The first topic is related to the ideas for this research. In order to design a new concept aerator, it needs to understand the behavior and habitat of tiger prawn in farming industry.

To design an aerator, it is necessary to understand how aerator works. It also relates to how dissolved oxygen can be generated by aerator. These two topics are the most important key need to understand in order to design the aerator. The only option for use in a shallow pond aerator is to use air diffuser aeration. This type of aerator is working by inject a bubbles of air from the bottom of the pond and do not damage the bottom of the pond. Unfortunately this type of aerator is inefficient and less water circulation. It makes it not suitable for large ponds.

Research on developed aerator more focus on increase it efficiency without consider the suitability of the aerator, especially aerator for shallow pond. Not many aerators are suitable to use for the shallow water. Since research in implement the flexible link in water is not widely done, and no aerator with this concept yet, this gives a good opportunity to optimize the advantages and capabilities of flexible link to become new concept aerator. It also gives an opportunity of aerator option

especially mechanical surface aerator type. Mechanical aerator type can offer a good aerator efficiency compare to diffuser air type. Tiger prawn production is increasing drastically from 1990 to 2010. Due to the constraint of aerators choices, agricultural industries have to choose paddlewheel aerators and design the pond with unnecessary depth just to prevent the bottom of the pond damage. This can cause a risk to tiger prawn if paddlewheel suddenly can't operate. Tiger prawn hard to go to the pond surface to breathe because it can't swim like a fish. By creating this new concept of mechanical aerators that can be used in a shallow pond, now the pond depth can design according the tiger prawn can breed. Besides, it also can reduce operational costs and contribute to profits.

2.2 Introduction to Tiger Prawn

Tiger prawn or giant tiger prawn also known as Penaeus Monodon is a marine crustacean that is widely reared for food. It inhabits the coasts of Australia, South East Asia, South Asia and East Africa. It shape is similar as other prawn. Adults may reach 33 cm in length and females are commonly larger than males. Research done by Holthuis (1980), found that the tiger prawn can grow-up to a large size with a weight up to 130 gram. The highest weight of tiger prawn will become more high value and demands in the international market.

Penaeus monodon mature and breed only in tropical marine habitats and spend their larval, juvenile, adolescent and sub-adult stages in coastal estuaries, lagoons or mangrove areas. Under natural conditions, the giant tiger prawn is more of a predator than an omnivorous scavenger or detritus feeder than other prawn. After moulting, the new shell is still soft which causes prawns to become vulnerable and they may subsequently be eaten by their predators or companions.

Fishery statistics from the Food and Agriculture Organization (FAO) of the United Nations (2006) shown more than a century, the prawn farming has been practiced for food and livelihood of coastal people in some Asian countries, such as Indonesia, the Philippines, Malaysia, Thailand and Vietnam. Originally the Penaeus monodon was harvested together with other shrimp species.

Figure 2.1 shows that the total aquaculture production of Penaeus monodon increased gradually from 21 000 tones in 1981 to 200 000 tones in 1988; then it sharply increased to nearly 500 000 tones with a value of USD 3.2 billion in 1993.

Since then, production has been quite variable, ranging from a low of 480 000 tones in 1997 to a high of 676 000 tones in 2001. The major producers of Penaeus monodon include Thailand, Vietnam, Indonesia, India, the Philippines, Malaysia and Myanmar (FAO Fishery Statistic, 2011).

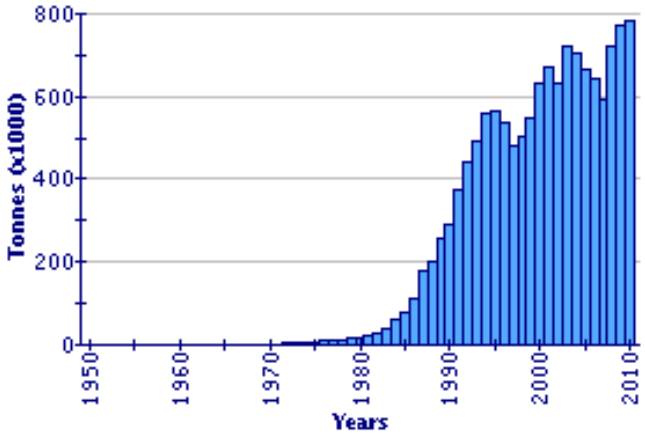


Figure 2.1: Global aquaculture production of Penaeus monodon (Food and Agriculture Organization of the United Nations)

In Malaysia and Asian as well, prawn farming business is the one of the major aquaculture industries. This production exponentially accelerated grows as the high demand either in domestic or global market. In achieving those demand, prawn farmers increase their production by creating more prawn pond, either earthen pond or indoor culture tank. However, the created pond has a problem because it out of the prawn's nature. There are a lot of factor needs to be considered acquiring good shrimp growth as well as the shrimp quantity. According the World Bank et al. (2002), some of these factors are water quality, feeding rate method, prawn diseases and predator threat, water quality one of the most influence factors for prawn farming. Several parameters must be controlled to obtain suitable water quality. The parameters involved are pH value, ammonium capacity, dissolved oxygen, water temperature, salinity and turbidity. This to match the natural prawn's habitat naturally controlled in an ecosystem. Specific mechanism is required to perform the right match of those parameters. The most important mechanism is an aeration system for sustain dissolved oxygen level.

Apud (1984) stated in his research, the breeding method can be categorized into three: extensive, semi-intensive and intensive. The extensive method commonly practiced for shallow pond between 40 to 70 cm designed with single gate to serve and supply and drain facilities. Capacities of tiger prawn under this method are limited for 2 to 3 prawn per square meter. Water management is totally depended on tidal fluctuation.

The semi-intensive culture method is highest method practiced breeding tiger prawn. This method can breed with capacity 10 to 30 prawns per square meter with the depth of pond are between 70 to 100 cm. To maintain the desired water quality and depth, the water pump is always used to operate especially during neap tide.

Intensive culture method basically practiced for larger scale for breeding tiger prawn. This method required higher capital investment and technology. Aeration device is fully dependent to generate dissolved oxygen, release toxic gases and mix water 24 hours a day. Even though the stocking density can rise between 100 to 200 prawns per square meter, it also contributes a high risk.

In aquaculture farming, poor dissolved oxygen control could become major factor of loss to the farmer. According to Pruder (1983), low levels of dissolved oxygen are commonly encountered in aquaculture ponds and result in instability, low productivity and some time mass mortality. Yuquan Li et al. (2006) indicated that dissolved oxygen below 2mg/L significantly reduce the growth rate of Penaeus vannamei and Penaeus Monodon. D'Abramo et al. (2003) reported that dissolved oxygen at 3 parts per million (ppm) are stressful, and lower oxygen concentrations can be lethal. De Bnath et al. (2013) in his research stated the dissolved oxygen is very important to aquatic farmer to enhance good prawn growth. Common dissolved oxygen level is varied between 4 to 9 ppm in semi intensive ponds and 4 to7 ppm in traditional ponds.

2.3 Dissolved Oxygen

Dissolved oxygen is refers to the oxygen that present in water. A dissolved oxygen level will determine the water quality. Shultz et al. (2011) stated that the dissolved oxygen is very important for the process of life. Lack of oxygen is not only a sign of pollution, it is also harmful to aquatic life. The dissolved oxygen is useful not only for humans but also for other organisms such as animals, insects and micro-

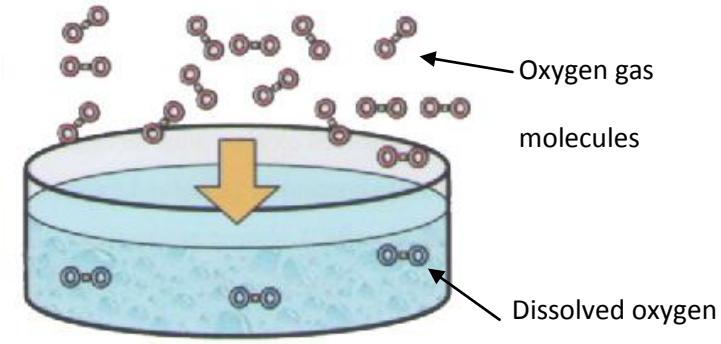
organisms including bacteria and phytoplankton. In many cases, dissolved oxygen must be controlled to ensure the proper breathing living thing continues. Dissolved oxygen concentrations are most often reported in units of milligrams of gas per liter of water - mg/L or parts per million – ppm.

Tchobanoglous et al. (2001) in their research stated that the important part of wastewater treatment process is oxygen transfer. It is the process by which oxygen is transferred from the gas to the liquid phase. To move a large quantity of oxygen required, additional interfaces are created using the aeration process to overcome the low solubility of oxygen and low oxygen transfer rate problems. To provide the required amount of dissolved oxygen, aerator system is always required. Janssen and Albrecht (2011) stated the aerator is the largest single cost in waste water treatment system. Concentration of dissolved oxygen is one of the most important quality parameters that affect the quality of the waste water.

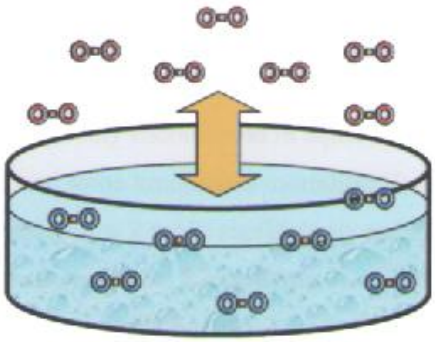
Oxygen is continuously moving between the water and the surrounding air. The behavior of oxygen gas is it tends to travel from high pressure volume to the low pressure volume. According Floyd (2011), there is three main sources of oxygen in the aquatic environment which are direct diffusion from the atmosphere, wind wave action and photosynthesis by aquatic plant. Oxygen molecules easy penetrate into the water until equilibrium of oxygen volume achieved when quality of water is good. The same thing might happen but in the opposite direction if the pressure of dissolved oxygen inside the water is higher than the atmosphere, it tends to disperse in the atmosphere. Boyd (1998) revealed that this equilibrium of oxygen volume is known as saturated concentration. Figure 2.2 shows the movement of high pressure oxygen molecules from atmosphere into an amount of water until equal value is reached. Boyd (1998) also reported that dissolved oxygen concentration in water at saturation varies with water temperature, salinity and barometric pressure.

Floyd (2011) and Boyd (1998) both also mentioned the low levels of dissolved oxygen are most frequently associated with hot, cloudy weather, heavy thunderstorms. At a given temperature, the dissolved oxygen concentration at saturation increases in proportion to increasing barometric pressure. However, dissolved oxygen concentration at saturation will decrease as salinity and water temperature increase.

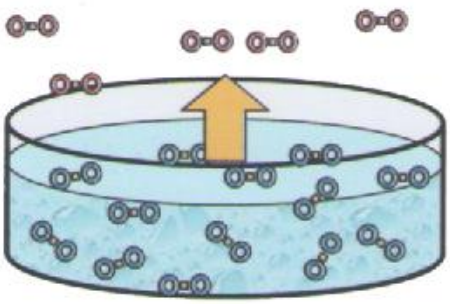
Murphy (2012) stated that the colder the water, the more oxygen can be dissolved in the water. In YSI Aquaculture (2010) application note informing that the water with temperature 32.C can hold up to 7.3mg/l of oxygen, while 7.C water can hold 12.1mg/l. When the water temperatures rise, oxygen levels will decrease. This is the reason why the dissolved oxygen concentrations at one location are usually higher in the winter than in the summer



(a) Deficit Dissolved Oxygen



(b) Saturated Dissolved Oxygen



(c) Supersaturated Dissolved Oxygen

Figure 2.2: Oxygen behaviour transfer into water

Dissolved oxygen in earthen prawn pond comes from two processes, physically and chemically. Physically, these oxygen molecules are entrapped in water with certain mechanism. For examples, through water fall, turbulence water flow and waves. Wave action and splashing allows more oxygen to be absorbed into the water. More of the water's surface area is exposed to the air; it will absorb more oxygen from the atmosphere than a calm, smooth body of water. This statement strongly informs by Pedersen (2000) in his paper where the gas such as oxygen are easily absorption into moving water Extensive prawn farming which has big surface pond area has the advantages for natural aeration. Boyd (1998) in his research found that the wind consumes 20.95 % of oxygen gas enter to water surface through waves. This is the idea behind aerators; by creating waves and expose more water surface area more oxygen can enter into water.

Meanwhile dissolved oxygen exists chemically as the result of photosynthesis process by aquatic plants. Pruder (1983) had revealed that algal photosynthesis and bacterial respiration are the major oxygen source and sink respectively. In the other hand, prawn respiration and atmospheric diffusion were found to play minor roles in the oxygen balance in the prawn pond.

2.4 Aeration

Kirke and Gezawy (1996) stated the problem of shortage dissolved oxygen in water can be prevented by circulation of mechanical means. This is called mechanical aeration. As mention early, water aeration is the net movement of oxygen from atmosphere which higher pressure into the surface water. To keep the aquatic environment safety, the aeration equipment becomes the prior device. Jensen et al. (1989) in their research stated that, the aeration is important to minimize stress associated with oxygen concentration lower than 4 ppm. It functions to increase the area of contact between air and water, so that oxygen can enter into water surface as mention by Petersen and Walker (2002). They also stated that the aerator function is similar as the 'lung' to pumping oxygen into water stripping carbon dioxide out especially for intensive aquaculture pond.

2.4.1 How Aerator Work

Aeration and circulation of the water is one of the most essential issues in intensive and semi-intensive aquaculture. Good aerator must capable to aerate and circulate water at the same time. Circulation of water encourages other harmful gases and excess nitrogen and carbon dioxide to escape from water to the atmosphere. In ponds, a number of functions are performed by a good aerator:

1. Directly adds oxygen to water (oxygenates).
2. Ensure the dissolved oxygen uniformly throughout the pond, circulates and mixes of water top to bottom. This important aspect when a bottom dwelling animal which cannot come to the surface.
3. Capable to moves aerated water away from the immediate area around the aerator, so that it not retreating the same water while dragging in unaerated water.

2.4.2 Common type of existing aerator

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. The types of aerator method can categories in three types (Thakre et al., 2008): -

1. Surface of mechanical aeration method, which increase interfacial area by spraying water droplet into the air.
2. Diffuser aeration method, which release bubble beneath surface of water.
3. Combine and turbine aeration method, which introduced larger air bubble into the water and reduce their sizes mechanically.

2.4.2.1 Paddlewheel.

Paddlewheel aerators are the most widely used method of aeration. Currently paddlewheel is the most efficient aerator due to the combined way it rapidly decertifies a pond through strong water circulation and aeration by spraying water into the air as well as dragging air into the water creating larger surface areas of air-water interface allowing efficient gaseous exchange for oxygen and release harmful gas to out. The combined effect of strong circulation and aeration allows the formation of the important oxidized surface sediment layer (Boyd, 1995).

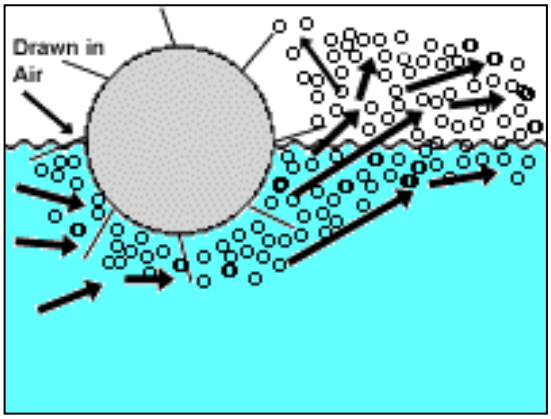


Figure 2.3: Paddlewheel **(**Boyd, 1995).

2.4.2.2 Diffuser Air and Air Lift

Boyd (1995) in his research found that the diffuser air and air lift a least cost efficient form of aeration. The efficiency of these types of aeration is depending on the size of the bubble. Because of the lower circulation of water, the numbers of air diffusers needs to scattered around a pond thus make it the most inefficient system. Shallow pond compressed air aeration system performed well but would probably not be suitable for crayfish production and this diffuser aerator is not suitable to use for tiger prawn breeding.

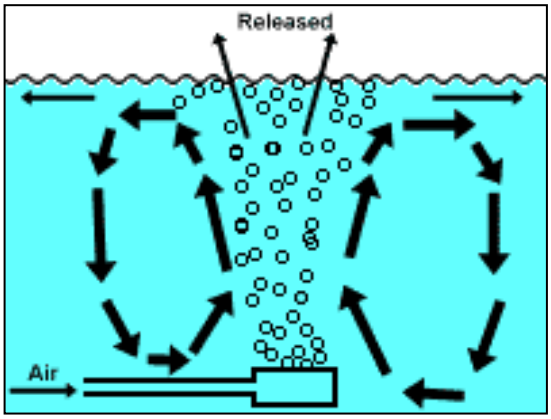


Figure 2.4: Diffuser Air **(**Boyd, 1995).

2.4.2.3 Propeller Aspirator Pump

Propeller aspirator pumps are good circulators and aerators in pond but the designed more for deeper water (1-5 meter). When used in shallow ponds, it have tendency to scour hollows where the water stream collides with the pond bottom so consideration must be taken when it installed as mention by Boyd (1995). These types of aerators would be more suitable for farm dam or harvesting operations that wish to increase production by providing additional feed although the cost of connecting main power is usually prohibitive.

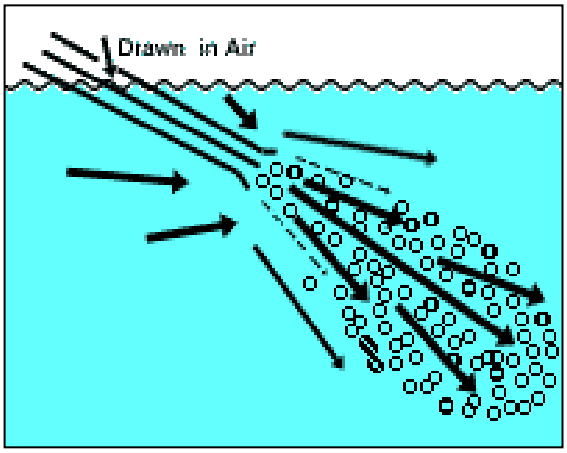


Figure 2.5: Propeller Aspirator Pump **(**Boyd, 1995).

2.4.2.4 Submersible Pumps

The use of submersible pumps near the bottom of a pond with the outlet pointed at the surface, depending on the size of the pump, provides some circulation and mixing of the pond water but like air diffusers this can be localized. It does not however add any oxygen directly to the water except through diffusion by exposing poorer quality water to the surface. If use this type of device it would be better to extend the outlet above the surface and provide a spray bar to spray the water back into the pond but this is an inefficient way to aerate a pond. This type of aeration is not recommended for large grow out ponds 1000m^2 but with the spray bar it is suitable in small broodstock and nursery ponds between 100 to 200m^2, (Boyd, 1995).

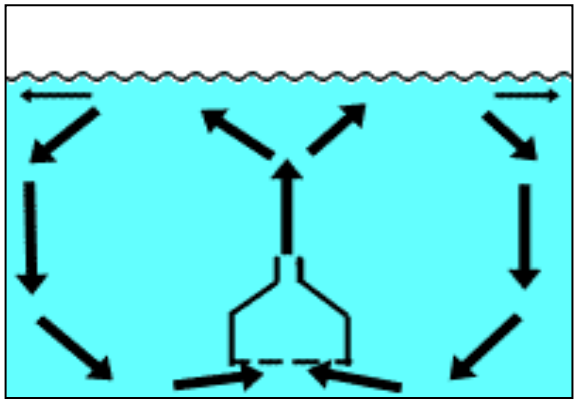


Figure 2.6: Submersible Pumps **(**Boyd, 1995).

According Rao and Kumar (2007), mechanical surface aerator is widely used from all these categories. This aerator offers a better efficiency and convenience operation and maintenance. Further the oxygen rate transfer from gas to liquid phase is dependent on various factors for given method of aeration such as dynamic variable like speed, mixing intensity and turbulence, geometrical parameters like size and number of blade, depth of flow and physicochemical properties of the liquid.

The different types of aerators practical is depending on it uses. Generally design of aeration system is depend on the total oxygen required in kilograms of oxygen per hour (kg O_2/hr). Table 2.1 shows the efficiency and performance of each type of aerators used for aeration for fish or prawn culture as well as wastewater treatment. Paddlewheel, propeller, aspirator, pump, vertical pump, pump sprayer and

diffuser air are typical aerators nowadays. Aerator got it name based on how it looks like and how it function.

Boyd (1990 & 1998) in his report also clarified the mechanical aeration method such as paddlewheel is more efficient compare the other aerator method. Fast et al. (1999) stated that paddlewheel aerators are the most common mechanical aeration device used in pond aquaculture today. Strengthen the statement, Peterson et al. (2001) in their report also stated the paddlewheel was the dominant aerator type in Australia. Rosso and Stenstrom (2006) in their research found the high turbulence associated with course-bubble aerators make them behave more like surface aerators that fine bubble aerators. But to create high turbulence aerators expense of greater energy density, and lower aeration efficiency.

The Department of Fisheries, Australia, (2001) stated the advantage of the mechanical aerator system is it can rapidly decertify a pond through strong water circulation and aeration by spraying water into the air and dragging the air into the water. This mechanism is totally providing large surface area of air contact with water.

Kirke and Gezawy (1997) in their research inform that when done a circulation of water from lower levels to the surface, it will become oxygenated by natural processes of diffusion, photosynthesis and wind and wave action. This method is better rather than mixing air into water which consumes energy through turbulence and does not add dissolve oxygen. The air and water interface is very significant for multiple gas exchange where oxygen molecules enter into the water and harmful gas will disperse out to the air. Besides, strong water circulation helps to dispersing the dissolved oxygen to whole pond as well as removing the unwanted waste and sludge to a certain place to be removed.

Table 2.1: Summary of Aerator Performance

Type of aerator	SAE (kgO_2 /kWh)	References
Low speed surface aerator	1.5 - 2.1	Gehring and Lindam (2014)
High speed surface aerator	1.1 – 1.4	Gehring and Lindam (2014)
Paddlewheel with curve blade	2.269 – 2.95	Bhuyar et al. (2009)
Paddlewheel	1.29 – 2.75	Cancino (2004)
Pump sprayer	0.9 - 1.9	Boyd (1998)
Diffused air	0.7 - 1.2	Boyd (1998)
Propeller aspirator pump	1.58	Boyd (1990)
Vertical pump	1.28	Boyd (1990)

2.5 Flexible link

Flexible link is one of the important parts in robotic manipulator research study. According Mansour et al. (2010), the flexible link has the advantages to 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. Ismail (2006) stated that the flexible plate structures are used now in diverse applications lead to the demand of having reliable, light and efficient flexible structures.

The advantage of flexible link also attracted many researchers to do research in this field such as Nikolaskopoulos and Tzes (2010) do a detail research in order to design and handle the system because the deflection effects. In book of compilation papers by Tokhi and Azad (2008), research in do the application of such system can be extensively found in various sectors such as in robotic, avionics, etc. This is due to the numerous advantages flexible link can offer compared to their rigid body counterparts. Meanwhile in latest research, Kumar et al. (2013), investigate to implement the flexible manipulator as space robot with two arms rigid-flexible that have scheme trajectory control at it tips.

According the Gümüşel and Özmen (2011), there are few researches done on underwater flexible manipulators. They do a research in this area since most of the deep undersea cannot be reached by human divers and because of inconvenient, dangerous deep sea environments, the use underwater manipulators has become vital tools for underwater remotely operated vehicle (ROV) operations. They mention, there are four different forces acting on the manipulator under the water which are buoyant force, drag force, lift force and the gravity force. The drag and lift forces are defined according to the moving object's velocity vector. The values of force depend on the geometry of the object. Followed by Nguyen et al. (2013) also do a research implement the flexible link as flexible tail fin for fish robot. They mention the other capability of flexible tail where it able to changing the body of fish robot shapes to generates propulsion forces which enable to move forward and backward. This advantage of movement only can be achieved by using flexible link.

According the Faria and Inman (2014), when a mechanical structural component is immersed in a fluid and it vibrates, the reasonable assumption is that part of the energy is transmitted to the adjacent media. They also mention, flexible link can be implementing as a fish like pulsating mechanism. By using a control algorithm, the elastic deformations of the endpoint of the link can be controlled thus the vibration of the flexible link can also be controlled. In this flexible link aerator research, the benefit of vibration that was produced by the flexible link has the potential to create waves and bubbles in the water. Thus, it can be manipulate to generate dissolved oxygen in water.

2.6 Open Loop Controller

An open-loop controller, also called a non-feedback controller, is a type of controller that computes its input into a system using only the current state and its model of the system. A characteristic of the open-loop controller is that it does not use feedback to determine if its output has achieved the desired goal of the input. This means that the system does not observe the output of the processes that it is controlling. Consequently, a true open-loop system can not engage in machine learning and also cannot correct any errors that it could make. It also may not compensate for disturbances in the system. The open loop control system are cheaper

and less complex then the closed loop control system, while the controlling efficiency of this system is nearly zero.

Lima et al. (2014) stated that, the open-loop control is useful for well-defined systems where the relationship between input and the resultant state can be modeled by a mathematical formula. For example determining the voltage to be fed to an electric motor that drives a constant load, in order to achieve a desired speed would be a good application of open-loop control. If the load were not predictable, on the other hand, the motor's speed might vary as a function of the load as well as of the voltage, and an open-loop controller would therefore be insufficient to ensure repeatable control of the velocity.

2.7 Research Gap

The tiger prawn can be breeding in shallow pond's water with a 40 cm of depth. However not many aerator are suitable to use for the shallow water. Aerator research only focus on how to increase aerator efficiency without consider the suitability of the aerator, especially aerator for shallow pond. Since research in implement the flexible link in water is not widely done, this gives a good opportunity to optimize the advantages and capabilities of flexible link to become new concept aerator. In previous mention, the mechanical aerator such as paddlewheel is more efficient in transfer oxygen rate into water rather than other aerator. The flexible link is suitable to become a new mechanical aerator.

In aquaculture industries, aerators become the most important component whereby the lack of dissolved oxygen can affect to the prawn grown and in the worst case it will fatal to the breeding. Low maintenance and high performance of aerator used, can contribute to the profit margin gain. In constraint situation to breed tiger prawn in pond, some of farming has to water pump aerator. It the only suitable aerator can be used for shallow pond. However it not efficient as mechanical aerator system, thus it will contribute more operational cost. To use paddlewheel, the pond needs to design specifically to avoid the bottom of the pond damage. It needs to consider the depth of water. The located aerators also need to arrange for ensuring the circulation of water is not affected if the pond is large and not damages the bottom of pond. Lack of circulation of water can contributes to bad quality of water.

Many researches also emphasize that, more water surface area contact to air and good water circulation will helping oxygen through into the water. These major factors exist in paddlewheel aerator system and made it the most efficient aerator and popular aerator device used. These determine that this factors need to be concern to develop a new aerator model; the aerator must capable to let more water surface area contact with atmosphere and at the same time it can circulate the water.

Thus this type mechanical system aerator will be used for design a new concept of aerator that will consider the water circulation and suit with a shallow pond for breeding tiger prawn. This research will implement the flexible link as the core mechanism to expose more water surface area contact to air and circulate the water. The previous existing flexible link mathematical model will be developing in purpose to develop a suitable mathematical model in new boundary condition.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Simulation and testing the actual aerator were carried out in order to achieve the goals of this research. Methodology works were emphasized further on system design, its functionality and reliability. In designing a new concept of aerator, it consists of construction of mathematical model, simulation and fabrication of actual model. The next page shows the description and overview the methodology in this research.

.

REFERENCES

Abd Rahman, I., Mat Suboh, S. and Arshad, M.R. (2007). Theory and design Issues of underwater manipulator. International Conference on Control, Instrumentation and Mechatronics Engineering (CIM'07), Johor Bahru, Johor, Malaysia, May 28-29, 2007

Apud, F.D. (1984). Extensive and semi-intensive culture of sugpo (Penaeus Monodon) in the Philippines. Proceedings of the National Prawn Industry Development Workshop, 10-13 April 1984, Iloilo City, Philippines. (pp. 55-73). Tigbauan, Iloilo,Philippines: Southeast Asian Fisheries Development Center, Aquaculture Department.

Ata A.A, Fares W.F and Sa'adeh M.Y (2012), Dynamic analysis of two-link flexible manipulator subject to different sets of conditions. International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012). Procedia Engineering 41 (2012) 1253-1260

Azad A.K.M., Tokhi, M.O., Mohamed, Z., Mahil, S. and Poerwanto, H. (1994). Finite Different and finite element simulation of flexible manipulators. Chapter 5, Flexible Robot Manipulators Modelling Simulation and Control. Published by The Institution of Engineering and Technology, London, United Kingdom 2008.

Banks, R.B. and Herrera Of (1977). Effect of wind and rain on surface reaeration, Journal of the Environmental Engineering Division, Vol. 103, No. 3, May/June 1977, pp. 489-504

Benson, T. (2010). Shape Effect on Drag, Retrieved from http://www.grc.nasa.gov/WWW/k-12/airplane/shaped.html. Last update Aug 23 2010. Access on June 2012

Billings, S.A and Voon, W.S.F. (1985). Correlation based model validity tests for non-linear models. Research report no. 285, Department of Automatic Control and System Engineering. University of Sheffield, U.K. International Journal of Control Volume 44, Issue 1, 1986.

Boyd, C.E. (1990). Water Quality in Ponds for Aquaculture. Birmingham Publishing Company, Birmingham, Alabama.

Boyd, C.E. (1995). Deep water installation of a diffused-air aeration system in a shallow pond. Journal of Applied Aquaculture. Volume 5, Issue 1, 1995.

Boyd, C.E. (1998). Pond Water Aeration System. Aquacultural Engineering 18, 9-40

Bugbee, B. and Blonquist, M. (2006). Absolute and Relative Gas Concentration: Understanding Oxygen in Air. Apogee Instruments, Inc.

Bhuyar L.B, Thakre S.B and Ingole N.W (2009), Design characteristics of curved blade aerator w.r.t aeration efficiency and overall oxygen transfer coefficient and comparison with CFD modeling. International Journal of engineering, science and technology Vol 1, no. 1, 2009, pp.1-15

Cancino, B., Pedro Roth, Manfred Reub, (2004). Design of high efficiency surface aerator, Part 1. Development of new rotor for surface aerators. Aquacultural Engineering 31, 83-98

Crank, J.and Nicolson, P. (1947). "A practical method for numerical evaluation of solutions of partial differential equations of the heat conduction type". Proc. Camb. Phil. Soc. 43 (1): 50–67

D'Abramo, L.R., Brunson, M.W and Daniels, W.H, (2003). Freshwater Prawns Pond Production and Grow-Out, Mississippi State University Coordinated Access to the Research and Extension System.

De bnath, P.P., Karim, M., Quazi, A.Z.M. and Kabir, K.E. (2013). Comparative Study on Growth Performance of Bagda (p. monodon, Fabricius, 1798) in Traditional and semi-intensive culture systems. Science and Technology 2013,3(1) 1-16

Department of Fisheries, Government of Western Australia. Published on Feb 2001. Retrieved on June 2012 from http://www.fish.wa.gov.au. Last Update 2004

Deyzen, A.V. (2008). A Nonlinear mathematical model of motions of planing monohull in head seas. Delft University of Technology, The Netherlands.

Faria, C.T. and Inman, D.J. (2014), Modeling energy transport in a cantilevered Euler-Bernoulli beam actively vibrating in Newtonian fluid. Mechanical System and Signal Processing 45 (2014) 317-329

Fast, A.W., Tan, C.E., Stevens, F.D., Olson, C.J., Jianguang Qin, Barclay, D.K. (1999). Paddlewheel aerator oxygen transfer efficiency at three salinities, Aquacultural Engineering 19, pg 99-103

Fishery statistics from the Food and Agriculture Organization (FAO) of the United Nations (2006, 2011). Retrieved on October 2012, from http://www.fao.org.

Floyd, R.F. (2011). Dissolved Oxygen for fish production, Fisheries and aquatic sciences department, Florida Cooperative Service, Institute of Food and Agricultural Sciences, University of Florida October 2011

Gehring M and Lindam J (2013), Energy-efficiency showdown: A comparison of aeration technologies. Water Online Digital Magazines December 2013 wateronline. epubxp.com/i/212760/26. Access on April 2014

Gümüşel, L. and Özmen, N.G. (2011). Modelling and control of manipulators with flexible links working on land and underwater environments. Robotica (2011) volume 29, pp, 461-470

Gresch, M., Armbruster, M., Braun, D. and Gujer W (2011). Effect of aeration patterns on the flow field in wastewater aeration tanks. Water Research 45 (2011) 810-818

Holthuis, L.B. (1980). FAO Species Catalogue. Vol. 1. Shrimps and prawns of the world. An annotated catalogue of species of interest to fisheries. FAO Fish. Synop. 125(1):271 p. Rome: FAO.

Ismail, R. (2006). Neuro Modelling and vibration control of flexible rectangular plate structure. Master thesis, Faculty of mechanical engineering, University Teknologi Malaysia. May 2006

Janssen, B. and Albrecht, T. (2011). Saving aeration costs. Water and wasterwater. Sulzer Techical Review 3/2011. Pg 6-10

Jensen, G.L., Joseph, D.B. and John, W.J. (1989). Pond aeration, types and uses of aeration equipment. Oklahoma Cooperative Extension Service, Oklahoma State University.

Kirke, B. and Gezawy, A.E, (1996), Design and Model Test for an Efficient Mechanical Circulator Aerator for Lakes and Reservoirs, Water Resource, Volume 31 pg 1283-1290

Kirke, B. and Gezawy, A.E, (1997), Mechanical circulator/aerator for lakes and reservoirs. Water Research Vol. 31, No. 6, pp. 1283-1290, 1997

Kumar, A., Pathak, P.M. and Sukavanam, N. (2013). Trajectory control of two DOF rigid-Flexible space robots by a virtual space vehicle. Robotics and autonomous System 61 (2013) 473-482

Lima, F., Kaiser, W., Da Silva, I.N., Azauri A.A. and de Oliveira Jr. (2014). Open-loop neuro-fuzzy speed estimator applied to vector and scalar induction motor drives. Applied Soft Computing 21 (2014) 469–480

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

Martinez F., Herrero, C.L and, Pablo, S.D. (2013). Open loop wind turbine emulator. Renewable Energy 63 (2013) 212-221

Md Zain, B.A.(2010), Dynamic Modeling of a Single-Link Flexible Manipulator Using Particle Swarm PhD thesis, Department of Automatic Control and Systems Engineering, The University of Sheffield, UK, 2010

Murphy, S. (2012). General Information on Dissolved Oxygen. Retrieved on May 2014 from http://bcn.boulder.co.us /basin/data/BACT/info/DO.html.

Nguyen, P.L., Do, V.P. and Lee, B.R. (2013). Dynamic modeling and experiment of a fish robot with a flexible tail fin. Journal of bionic engineering 10(2013) 39-45

Nikolaskopoulos, G. and Tzes ,A. (2010). Application of adaptive lattice filter for modal parameter tracking of a single flexible link carrying a shifting payload. Mechanical System and Signal Processing 24 (2010) 1338-1348

Payo, I., Feliu, V. and Cortazar, O.D. (2009). Fibre Bragg rating (FBG), sensor system for highly flexible single link robots. Sensors and actuators 150 (2009) 24-39

Pedersen, T. (2000). Oxygen absorption into moving water and tenside solutions. Water Research Vol 34. No. 9, pp 2569-2581, 2000

Petersen E.L., Walker M.B, (2002), Effect of speed on Taiwanese Paddlewheel aeration, Aquacultural Engineering 26, 129-147.

Peterson, E. L., Wadhwa L.C. and Harris, J.A. (2001), Arrangement of aerators in an intensive shrimp growout pond having a rectangular shape, Aquacultural Engineering 24, pg 51-65

Pruder, G.D. (1983). Biological Control of Gas Exchange in Extensive Aquatic Production System, IEEE, OCEANS. Volume 15, August 1983, pg 1002-1004

Rao, A.R. and Kumar, B. (2007). Neural Modeling of Square Surface Aerators, Journal of Environmental Engineering, 133 (4). pp. 411-418

Rogers, L.G. (2001). Aeration Offers Dealers More Than They May Realize, Vol 43 No. 6, June 2001

Rosso, D. and Stenstrom, M.K. (2006). Surfactant effects on α-factors in aeration system. Water research 40 (2006) 1397-1404

Rubinstein, D. (1999). Dynamics of a flexible beam and a system of rigid rods, with fully inverse (one-sided) boundary conditions. Computer Methods Application Mechanical Engineering, 175 (1999) 87-97

Salleh, M.Y. (2007). Finite Difference simulation of a flexible rectangular plate structure. Master thesis, Faculty of mechanical engineering, University Technical Malaysia Malacca, April 2007.

Shultz, A.D., Murchie, K.J., Griffith, C., Cooke, S.J., Danylchuk, A.J., Goldberg, T.L. and Suski, C.D (2011). Impacts of dissolved oxygen on the behavior and physiology of bonefish: Impications for live-release angling tournaments. Journal of Experimental Marine Biology and Ecology 402 (2011), 19-26.

Tchobanoglous, G., Burton, F.L. and Stensel, H.D (2003). Wastewater Engineering; Treatment disposal and reuse. Metcalf and Eddy Inc..Published by McGraw-Hill Education, 2003 - Technology & Engineering.

Tokhi, M.O. and Azad, A.K.M. (2008). Flexible Robot Manipulators Modelling Simulation and Control. Published by The Institution of Engineering and Technology, London, United Kingdom 2008. ISBN 978-0-86341-448-0

Thakre, S.B., Bhuyar, L.B. and Deshmukh, S.J. (2008). Effect of different configurations of mechanical aerators on oxygen transfer and aeration efficiency with respect to power consumption. International Journal of Aerospace and Mechanical Engineering 2:2 2008.

Vidoni, R., Gasparetto, A. and Giovagnoni, M. (2013). Design and implementation of an ERLS-based 3-D dynamic formulation for flexible-link robots. Robot and computer-Intergrated Manufacturing 29 (2013) 273-282

Wasner, G.M., Ewing, J.J., Lineck, T.S., Jr. and Hinrichs, D.J. (1977). Energy Conservation in municipal waste watertreatment. EPA-130/9-77-011, NTIS No PB81-165391, U.S. EPA Res., Washington, D.C

World Bank, NACA, WWF and FOA (2002). Shrimp Farming and the Environment "Can Shrimp Farming Be Undertaken Sustainably?" A discussion paper design to assist in the development of sustainable shrimp aquaculture

YSI Aquaculture (2010). Dissolved oxygen management and related costs in pond aquaculture. Retrieved on May 2014 from http://www.ysi.com/media/pdfs/A564-DO-Costs-in-Aquaculture.pdf

Yuquan Li, Jian Li and Qingyin Wang, (2006). The effects of dissolved oxygen concentration and stocking density on growth and non-specific immunity factors in Chinese shrimp, Fenneropenaeus chinensis, Aquaculture 256 (2006) pg 608-616