STUDY ON THE EFFICIENCY OF FABRICATED AERATORS AND ITS INFLUENCE ON DISSOLUTION OF OXYGEN IN POND WATER

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NOVEMBER, 2018

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Thesis submitted to the Karnataka Veterinary, Animal and Fisheries Sciences University, Bidar in partial fulfillment of the requirements for the award of the

Degree of

MASTER OF FISHERIES SCIENCE

In

FISHERIES ENGINEERING AND TECHNOLOGY

By

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CERTIFICATE

This is to certify that the thesis entitled **"STUDY ON THE EFFICIENCY OF FABRICATED AERATORS AND ITS INFLUENCE ON DISSOLUTION OF OXYGEN IN POND WATER"** submitted by **Mr. MALOTH MOHAN, I.D. No. MFK- 1620** in partial fulfillment of the requirements for the award of Master of Fisheries Science in Fisheries Engineering and Technology of the Karnataka Veterinary, Animal and Fisheries Sciences University, Bidar is a record of bonafide research work carried out by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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DEDICATED

TO

MY BELOVED PARENTS, TEACHERS, SISTER

AND

MY PARTNER

ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

Words are few to express the feelings of thanks and gratitude to the following persons. First and foremost, I thank my **Almighty**, who is benevolent, beneficent and whose blessings have solely contributed to my success during my dissertation and till this phase of life.

It is my great privilege to work under the guidance of **Dr. S. Varadaraju,** Professor and Head, Department of Fisheries Engineering and Technology, College of Fisheries, Mangaluru to whom I owe my deepest respect and love. I wish to express my sincere thanks for his guidance, suggestions and constant support in every step of my research work. His careful guidance, love and affection during the master's program cannot be evaluated. It would have been impossible for me to do this work without his wise counsel and inflicting faith in me.

It is my proud privilege to express heartfelt gratitude to my Advisory Committee Members **Dr. E.G. Jayaraj**, Professor and Head, Department of Aquaculture, **Dr. Ganapathi Naik. M,** Professor, Department of Aquaculture, **Sri. Shashidhar. H. Badami**, Associate Professor, Department of Fisheries Engineering and Technology and **Dr. Jaya Naik,** Assistant Professor, Department of Fisheries Engineering and Technology for their timely scholastic guidance, ceaseless encouragement, innovative ideas, suggestions and critical evaluations throughout the course of work and without whose relentless effort it would have been difficult for me to carry out my research work.

It's my proud privilege to express my profound sense of gratitude towards **Dean,** College of Fisheries, Mangaluru for his generous help and facilities provided for the Programme.

I would also like to express my gratitude to **Narayana Anna**, Carpenter for fabrication of aerators for this study.

I fell short of words to express my wholehearted gratitude to my mother **M. Saroji**, dad **M. Devula** and sister **M. Jyothi**, whose unfeigned love, empathy, sky high inspirations and for being the guiding force of my life, propelling me towards brighter horizons of happiness and support me in all stages of my life and career and showed me right way during every bad phase in my life.

I am very much thankful to my life partner **M. Sandya** for her love, understanding, prayers and continuing support to complete this research work. I express my sincere thanks to her for co-operation, kind support and timely help during the course of my research work.

I would like to thanks my friends **Magaraju, Akila, Devika, Nandhini, Poulraj, Gajendra, Bharath, Madhukar** and batchmates for their constant encouragement.

I am at a loss of words to express my thanks to my friends for their sincere friendship and support made me more confident and give a happier and memorable stay in College of fisheries, Mangaluru.

I am extending my sincere thanks to my well-wishers and seniors **S. Vijay Kumar Reddy** sir, **P. Anand Prasad** sir, **China Rajesh** sir, **Dinesh** sir, **Sanjay** sir, **Kiran** sir, **Srinu Nayak** sir and **Reddya Naik** sir, for their love and genuine support.

I am deeply indebted to my juniors, **Lokesh, Tejaswin, Prashanth, Nandhan, Ashish, Karthik Gowda, Umesh and Rudresh** for their invaluable support and encouragement for the smooth completion of my work.

I would like to acknowledge the partial funding support for the research work provided by **KVAFSU,** Bidar under SCSP/TSP grant.

I am indebted to all who helped during my dissertation, without their help it would not as easy as to complete my research work.

Mangaluru
November, 2018

(MALOTH MOHAN)

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LIST OF SYMBOLS AND ABBREVIATION

DO	Dissolved Oxygen
mg/l	Milli gram per liter
ppm	Parts per million
O_2	Oxygen
N_2	Nitrogen
Ar	Argon
CO_2	Carbon dioxide
m	Meter
%	Percentage
BOD	Biochemical Oxygen Demand
RPM	Revolution Per Minute
PTO	Power Take Off
Kg O_2	Kilo gram oxygen
kW	Kilo Watts
SOTR	Standard Oxygen Transfer Rate (kg O_2/h)
SAE	Standard Aeration Efficiency (kg O_2/kWh^{-1})
AE	Aeration Efficiency

CRWR	Cage Rope Wound Rotor
CFR	Cage Fin Rotor
CBR	Curved Blade Rotor
Hp	Horse Power
SR	Sediment Respiration
WR	Water Respiration
CSC	Circular Stepped Cascade
PCSC	Pooled Circular Stepped Cascade
E	Efficiency
δ	Percentage of oxygen absorption
MBG	Micro Bubble Generator
ASCE	American Society of Civil Engineers
α	Angular position of propeller shaft
N	Rotational speed of propeller shaft
d	Submerged depth of propeller
GI	Galvanized Iron

APHA	American Public Health Association
DO_s	DO concentration at saturation (mg/l)
DO_m	Measured DO concentration (mg/l)
$K_L\, a_T$	Overall oxygen-transfer coefficient (hr^{-1}) at temperature T
Ln	Natural logarithm
OD_{10}	Oxygen deficit at 10 % saturation (mg/l)
OD_{70}	Oxygen deficit at 70 % saturation (mg/l)
$K_L\, a_{20}$	Overall oxygen-transfer coefficient at 20 °C ($hour^{-1}$)
T	Water temperature (°C)
Cs_{20}	DO concentration at saturation (20 ^{0}C)
V	Volume of tank (m^3)

INTRODUCTION

I. INTRODUCTION

Dissolved oxygen (DO) concentration is the most important and critical water quality parameter because of its direct effect on the feed consumption and metabolism of aquatic animals as well as indirect influence on the water quality. Oxygen remains in water in dissolved form as dissolved oxygen (DO). Aquatic animals and organisms in water require oxygen for respiration and other biological activities. One can expect that a decrease in the rate of the oxygen production by phytoplankton may have catastrophic consequences for life on earth, possibly resulting in mass extinction of organisms. Besides having capabilities to produce oxygen, planktonic community also depends on the oxygen availability and its confounding factors. Phytoplankton produces oxygen due to photosynthesis during the day, but consumes it through respiration during the night. Oxygen consumption by plankton is a function of DO levels that depends on temperature. The DO of water increases with increasing atmospheric pressure while it decreases as the temperature and salinity increases. In warm water with increasing temperature, oxygen depletion may arise because of a simple physical property of water. The warmer the water, the less dissolved oxygen it can hold.

Depletion of oxygen occurs mainly due to decomposition of organic matter, rate of evaporation and also consumption by aquatic animals. In intensive fish culture, considerable quantity of feed and fertilizer are used for rapid growth of fish, but the organic matter like fish excreta need large amount of oxygen for their decomposition. This organic matter is decomposed by aerobic bacteria. These bacteria survive in the presence of oxygen. They absorb oxygen for the process of decomposition of organic matter and ultimately the dissolved oxygen level reduced.

With high stocking and feeding rates maintaining optimum dissolved oxygen level in pond water for high production of shrimp or fish for maximum profitability are not just possible without proper aeration. Oxygen is more important in intensive fish culture because the speed with which it can change over a matter of hours or sometime even minutes. Dissolved oxygen concentration can change from optimum to lethal levels. The combination of these factors such as limited solubility, rapid use and slow replenishment can cause rapid changes in dissolved oxygen concentration (Hargreaves and Tucker, 2002). Aquaculture ponds may experience oxygen depletion at any time of the year, depending on the weather and amount of nutrient enrichment the pond has received; however, most oxygen depletion occur in warm weather and usually follow a period of cloudy, overcast conditions.

Most of the warm water species can survive long period at dissolved oxygen concentration of 2 to 3 mg/l (Boyd, 1982) but cold water species require a minimum of 4 to 5 mg/l. A minimum criteria of 6 mg/l is recommended for all juvenile fish and crustaceans. Aquaculture ponds require artificial aeration when stock biomass exceeds the natural re-aeration and delivered by wind photosynthesis and water exchange (Boyd, 1998). In production ponds dissolved oxygen concentration may decrease by 5-10 mg/l at night and in un-aerated ponds dissolved oxygen concentration at sunrise may be less than 2 mg/l (Boyd, 1990). Such low dissolved oxygen concentration can cause stress or mortality in culture organisms. Therefore, identification of potential threats to the oxygen content and availability for planktonic community in the water is literally an issue of vital importance. Oxygen depletion refers to low levels of DO and may result in fish mortality. When organisms die from oxygen depletion, there can be serious financial consequences for commercial aquaculture operations (Sallenave, 2013).

1.1. Aeration

Aeration is the process of mixing air with water to increase the dissolved content in the pond water. Aeration is the most effective means of increasing the dissolved oxygen concentration of culture water. It can increase the carrying capacity of the aquaculture system. It has also been used to improve water quality and increase yield in aquaculture ponds. Aerators serve as the lungs of an intensive aquaculture pond for pumping oxygen into the water column and stripping carbon dioxide out. Aerators perform two basic functions; they oxygenate water and also induce water circulation. These two functions are important in pond aquaculture because of better water and soil quality in response to aeration, fish eat better, have greater resistance to diseases, suffer less mortality and achieve better feed conversion efficiency in aerated ponds than in ponds without aerators.

Artificial aeration means using a mechanical device to bring oxygen levels to the point which ensures the health of the species while maximizing the production goals of the farm. Today's high intensity farms depend upon accelerated biological activity which tends to outstrip the natural oxygen supply. Artificial aeration then becomes a basic factor in production. Not only does it play a life-saving role in the health of the species, but also a life-saving role in the economics of the farm. Most owners of large aquaculture farms know the importance of oxygen and employ some artificial means to increase it. Probably the most common type of pond aeration system used by these farmers is some version of the paddle wheel.

The focus of pond aeration is not a matter of just trying to increase the oxygen levels but of regulating and monitoring the dissolved oxygen content. For example, if the oxygen content falls below 20 %, food intake can drop below optimal levels. If the oxygen level is too high, say over 100 %, it can force increased respiration and other problems. Thus, oxygen regulation plays a direct role in the economics of production. One reason oxygen monitoring is critical due to that wind action can play a big role in oxygen content. During times of high winds it might be possible to reduce mechanical aeration to save on utility costs. Strong winds blowing over large ponds can diffuse upto 4.8 g/m^2/day of oxygen into the water. The effect is less noticeable on small ponds where diffusion accounts for only 1.5 g/m^2/day of oxygen.

1.2. Types of Aerators

Various types of aeration systems, i.e., aerators have been developed over the years in an effort to improve the energy efficiency of the oxygen mass transfer process. These aerators work mainly on two principles (a) aeration by splashing water into air i.e. paddle wheel aerator, vertical pump, pump sprayer, gravity aerators etc. (b) aeration by bubbling air into water i.e. propeller aspirator, diffused aeration system etc. In aquaculture, propeller-aspirator-pump aerators, vertical-pump aerators, diffused air aeration systems and paddle wheel aerators are widely used. Cascade aerators, a type of gravity aerators are generally used as pre or post-aeration system. If site constraints and hydraulic conditions permit gravity flow is the least costly method to raise DO levels with the use of cascade aeration system (Tchobanoglous *et al.*, 2003).

Rappaport *et al*. (1976) reported five methods of aeration to determine its effectiveness and obtained best results with paddle wheels and the spray type surface aerators. The higher fish yield were obtained with the spray type surface aerators but paddle wheel aerators were found most effective in increasing oxygen concentration and commonly used for emergency aeration. In aquaculture system several methods have been used to increase DO concentration in ponds. In which pond aeration systems have been very popular in the field of aquaculture during the last decade.

1.3. Aerator performance test

Aeration performance testing has been important in selecting design features to provide cost effective and for efficient aquaculture pond aerators. Mechanical aeration is the most common and usually the most effective means of increasing dissolved oxygen concentration in ponds. All basic types of mechanical aerators have been used in aquaculture but vertical pumps, pump sprayers, propeller aspirator pumps, paddle wheels and diffused air systems are most common in pond aquaculture. Gravity aerators, nozzle aerators and pure oxygen contact system are used in fish and crustaceans hatcheries and in highly intensive production system such as race ways and in tanks. Amount of aeration vary from as little as 1-2 kW/ha in some types of fish culture to as much as 15 or 20 kW/ha in intensive culture of marine shrimp. Calculations suggest that about 500 kg additional production of fish or crustaceans can be achieved per kW of aeration.

1.4. Scope of the present study

Recent studies suggested that the use of heavy aeration to provide the greatest possible production is less profitable than moderate aeration to improve water quality and enhance the feed conversion efficiency. Further, the development of automatic devices to start and stop aerators in response to daily changes in dissolved oxygen concentration are improving, but they are expensive and nor completely reliable. Aeration cost is the third largest cost in intensive aquaculture system after post larvae and feed cost representing about 15% of total production cost (Kumar *et al.*, 2013). The cost of the mechanical aerators is more and it requires more operational and maintenance cost. So by keeping the above points in view the present study was carried out for designing, fabricating, testing the efficiency of low cost fabricated aerators and also study its influence on dissolution of oxygen in pond water.

1.5. Objectives

1) Designing and fabrication of aerators.

2) To study the increase in dissolved oxygen content in the pond water.

3) To study the efficiency of fabricated aerators in pond water.

4) To study the influence of aerators on oxygen dissolution in pond water

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Dissolved oxygen is one of the most essential and primary limiting factor controlling the growth and survival of fish. Dissolved oxygen denotes the oxygen present in water. The dissolved oxygen level will determine the water quality. Shultz *et al.* (2011) described that, the dissolved oxygen is very significant for the process of life. Dissolved oxygen concentration measured either milligrams of gas per liter of water (mg/l) or parts per million (ppm). Baker *et al*. (2014) reported that, dissolved oxygen levels may also be measured as percent saturation (i.e., a relative measure of the amount of oxygen dissolved in water). The equilibrium of oxygen volume is known as saturated concentration Boyd (1998) and also mentioned that dissolved oxygen concentration in water at saturation differs with water temperature, salinity and barometric pressure.

2.1. Sources of dissolved oxygen (DO)

The major reservoir of oxygen in a natural setting is the atmosphere. Any given quantity of the air we breathe is composed of about 20.946 % oxygen gas (O_2), 78.084 % nitrogen (N_2), 0.934 % argon (Ar), 0.032 % carbon dioxide (CO_2) and a trace of other gases (Colt, 1984). Oxygen dissolves into water from the following main sources (i) the atmosphere (ii) wind and wave action (iii) as a product of photosynthesis by aquatic plants, algae and some bacteria.

Atmospheric oxygen enters water by diffusion or turbulence related with physical agitation of surface water. Direct diffusion is a very slow process because oxygen is slightly soluble in water. Thus, surface agitation by wind or other means that mixes air and water together is the most effective way to add atmospheric oxygen into the water column. The process of mixing air with water to rise DO content is known as aeration.

Oxygen production by photosynthesis in aquatic plants and organisms is the primary source of DO in pond aquaculture systems. Photosynthesis in an aquaculture pond is fueled by light energy from the sun. Chlorophyll-bearing aquatic organisms like submergent and emergent plants, phytoplankton and photosynthetic bacteria transfer oxygen into the water column as long as light is available.

2.2. Requirement of dissolved oxygen for fish

A minimum DO concentration of 5 mg/l is recommended for optimal freshwater fish health (McKee and Wolf, 1963; Swingle, 1969) and mortalities may occur if DO concentration is prolonged less than 2 mg/l (Noga, 2010). Critical DO levels are species-specific; however, DO levels at or near saturation (7.8 mg/l at 28°C) are recommended for most ornamental fish species (Lawrence, 2007). Low DO concentrations have been linked to decreased hatching and growth rates, lower feed consumption and even mass mortality events in extreme cases (Brungs, 1971; Buentello *et al*., 2000; Das *et al*., 2012).

2.3. Dissolved oxygen (DO) dynamics in ponds

DO is the most precarious and probable element of water quality in any aquaculture operation because all aerobic aquatic organisms need a continuous supply of DO to survive. Subsequently, a basic understanding of the mechanisms of oxygen production, transfer and reduction is necessary to aid aquaculturists in the successful management of pond growing systems. While some variables upsetting DO dynamics are not simply influenced by pond managers, many factors can be manipulated to recover water quality conditions for successful production. The dynamics of dissolved oxygen in fish ponds is very complex. Then the decision of when and where to check DO in ponds varies among fish farmers, but experience dictates that DO be checked several times daily. DO measurement should made at least three times during the warmer months, at dawn, at dusk and about four hours after dusk (Tucker and Robinson, 1990) and also stated that many producer do not measure DO during the winter. However, since DO dynamics is a common function of temperature, depletions can occur during periods of unseasonably warm weather during winter months.

2.4. Gas exchange and oxygen concentration in water

Oxygen as a gas has a low solubility in water. In addition, the amount of oxygen contained in water varies with temperature and salinity in a predictable manner. Less oxygen can be held in fully air-saturated warm sea water than fully air-saturated cold freshwater. While the oxygen content of the water sets the absolute availability of oxygen in the water, it is the oxygen partial pressure gradient that determines how rapidly oxygen can move from the water into the fish's blood to support its metabolic rate. This is because oxygen moves by diffusion across the gills of fish. According to Fick's law of diffusion, the rate of diffusion of oxygen across the gills is determined by the gill area, the diffusion distance across the gill epithelia, the diffusion constant and the difference in partial pressure of oxygen across the gills (Crampton *et al*., 2003).

2.5. Effects of oxygen concentration on fish

It is commonly thought that if there is an insufficient oxygen in the water, the fish will be seen gasping at the surface but this is a last resort means to breathe. There may be a dissolved oxygen problem in the water then the fish become unusually lethargic and stop feeding. This is the first indication shown by fish. As oxygen level decrease, the fish do not have enough energy to swim and feeding utilizes yet more oxygen. Increasing the aeration will certainly make the environment more comfortable for the fish, even if the dissolved oxygen level was already satisfactory.

The dissolved oxygen concentration requirements for different species are as follows:

Cold water fish - 6 mg/l

Tropical freshwater fish- 5 mg/l

Tropical marine fish- 5 mg/l

These values are minimum requirements for healthy growth, tissue repair and reproduction (Svobodova *et al*., 1993). Most of the fish species will tolerate a drop of DO below these minimum values for a short period of time, probably the cold water species are likely to tolerate a lower level than tropical fish. However, the period of time during which the oxygen level drops below the required minimum level, will cause the fish to become stressed. It may take the fish several days to recover from short term oxygen depletion but where the levels are persistently low, an assortment of stress related diseases such as fin rot and white spot may occur.

2.5.1. Fish response to hypoxia

Hypoxia or oxygen depletion is a phenomenon that occurs in aquatic environment as dissolved oxygen becomes reduced in concentration to a point detrimental to aquatic organisms living in the system. In an aquatic system lacking of the dissolved oxygen (0 % saturation) is termed as anaerobic condition. Reducing or anoxic is a system with a low DO concentration in the range between 1 % and 30 %. Most fish cannot live below 30 % DO saturation. A "healthy" aquatic environment should seldom experience DO of less than 80 %.

Some species are much more tolerant of hypoxia than others, leading to differential survival during extended periods of hypoxia (Poon *et al*., 2002). To avoid this, aquaculture systems have to be supplied with enough oxygen saturation. However, too much oxygen is also harmful to fish.

2.5.2. Fish response to hyperoxia

Hyperoxia is the state of water when it holds a very high amount of oxygen. At this state, water is described as dissolved oxygen content saturation is greater than 100 %, this percent can be 140-300 %.

At this water condition, oxygen molecules will begin to move around within the water column looking for a little elbowroom. If it is not available, it will return to the atmosphere or attach to the organisms around (Florida Lake Watch, 2004). If fish are exposed (at a lower atmospheric pressure) to such water, their blood equilibrates with the excess pressure in the water. Bubbles form in the blood and these can block the capillaries; in sub-acute cases the dorsal and caudal fin can be affected and bubbles may be visible between the fin rays.

Some species such as salmons and fast swimming fishes, the swim bladder acts like an oxygen store to be used during the hypoxia. When the gads level in the blood is high, gases will diffuse from the blood to the bladder. When the water is supersaturated (hyperoxia) the bladder becomes over-inflated and this leads to buoyancy problems especially in small fishes (Groot *et al*., 1995).

2.6. Oxygen balance and stratification

The quantity of oxygen required for microbial activity is known as biochemical oxygen demand or BOD. The pond or lake which is not used for aquaculture, the source of DO produced by photosynthesis or diffused from the atmosphere usually beats the amount required by respiration and BOD. However, the biomass of plants, animals and microbes in an aquaculture pond is usually much higher than in natural waters, so oxygen is sometimes consumed faster than it is produced. Environmental factors, such as barometric pressure and altitude, can further affect DO balance in a pond, but temperature is likely the most influential variable. Warm water holds much less DO than cool water because the solubility of oxygen decreases with increasing temperature. In addition, increasing temperature accelerates the factors like respiration rates and BOD that remove DO from the water column (Boyd and Lichtkoppler, 1979; Boyd, 1998).

The upper layer of a pond absorb sunlight and heat and the ability of light to penetrate into the water column declines exponentially with depth. In addition, other factors like turbidity from suspended sediment or high algae concentrations further decrease the intensity of sunlight at deeper portion. In a pond, the warmest water is found at the surface and temperature generally decreases with depth. This layering of pond water, with less dense warm water “floating” on top of denser cold water, is known as thermal stratification. The degree to which a pond stratifies is largely driven by depth, surface area open to mixing by wind or mechanical means and the relative biomass of plants and animals in the water column that might influence photosynthesis or decomposition rates (Hargreaves, 2003). During the summer months, shallow aquaculture ponds (e.g., 3 to 8 feet deep) may stratify during the day and destratify or equalize water temperature from top to bottom by mixing at night. Ponds deeper than 10 feet may not fully mix during the night, causing the persistence of a layer of cold water with very low DO near the bottom. Dissolved oxygen can also become stratified in a pond ecosystem and the process and degree to which this occurs is closely tied to the same factors that drive thermal stratification dynamics. Increased sunlight intensity near the surface of the pond drives greater algal photosynthetic rates which increases DO concentration. Thus, surface water usually contains much more DO than water near the bottom of a pond. For example, on a calm sunny summer afternoon, the DO concentration at the surface of a pond can be more than three times higher than the DO concentration along the bottom (Hargreaves, 2003). The element to which a pond exhibits oxygen (and temperature) stratification is correlated to depth; deeper ponds show greater variances in DO from top to bottom. Dissolved oxygen concentration in the bottom of an aquaculture pond can be low enough to prevent aquatic animals from living in it. This poses an obvious problem for some cultured species, such as crayfish and prawns that live on or near the bottom but it is also a major issue for finfish that are forced to positions higher in the water column where mortality from disease, cannibalism and predation from avian predators decreases production. Moreover, reduced water quality factors like low DO concentration can limit yield as animals expend energy on survival instead of weight gain and growth.

2.7. Dissolved oxygen for production

Managing an aquaculture pond for optimal production of shellfish, crustaceans or finfish requires maintaining DO within a range of values that encourage healthy and rapid growth. Dissolved oxygen level in aquaculture ponds manage the metabolism and growth of aquatic organisms. Each species has somewhat different DO requirements depending on developmental stage, water chemistry and other environmental factors. (Kutty, 1968; Tucker and Hargreaves, 2004; Hargreaves and Tomasso, 2004).

2.8. Aeration

The process of mixing air with water to increase the DO content in the pond water is known as aeration. Kirke and Gezawy (1996) stated that the shortage of dissolved oxygen in water can be prevented by circulation of mechanical means, this is called as mechanical aeration. As mentioned initially, water aeration is the net movement of oxygen from atmosphere with higher pressure into the surface water. To keep the aquatic environment safely, the aeration equipment becomes the prior device. Jensen *et al*. (1989) with their investigation stated that, the aeration is significant to minimize the 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 detailed that the aerator function is similar as the ‘lung’ to driving oxygen into water, stripping carbon dioxide out particularly for intensive aquaculture pond.

2.9. Principles of aeration

Aerating an aquaculture pond water basically involves transferring gaseous oxygen from the large reservoir in the atmosphere into the water of the pond, where DO concentrations have dropped to critical levels (Boyd, 1998). Aerators help to mix pond water which can reduce thermal stratification and improve other water chemistry factors, most notably DO content. Finally, mixing by aeration can minimize organic matter accumulation that may increase BOD, reduce the density of algal blooms that can lead to oxygen depletion and fish health issues and shift the composition of algae blooms that may lead to flavor issues in finfish (Hargreaves, 2003).

2.10. Types of pond aerator

Aeration is not new to aquaculture, but over the past few years interest in this process has been increased enormously. 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 technique can classified in three types (Thakre *et al*., 2008)

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

2.10.1. Paddle wheel Aerators

Paddle wheel aerators are the most broadly used method of aeration. These aerators consist of an arrangement of paddles attached to a rotating drum or shaft. The pattern, length and shape of the paddles affect the aeration efficiency of the unit. They are considered as one of the most energy efficient device for increasing dissolved oxygen. They splash water into the air as the paddle wheel rotates. The splashed water comes in contact with air and falls back into the pond and thereby increasing the dissolved oxygen. Besides increasing the dissolved oxygen they also increase both horizontal and vertical movement of pond water. The combined effect of strong circulation and aeration allows the formation of the important oxidized surface sediment layer (Boyd, 1995).

2.10.2. Diffused-air aeration systems

Diffused-air aeration system use air compressors or blower to supply air and diffusers, porous pipe or other devices to release air bubbles into the water. Glass-bonded and silica stones are the most commonly used diffusers, however these diffusers constructed of porous plastic, synthetic perforated membranes and ceramic are also used (Boyd, 1998; Tucker, 2005). These are available in various shape and size such as rectangular or square stones, round or square disks or elongated tubes and pipes. The efficiency of diffused-air aeration systems is primarily a function of bubble size and diffuser depth. Diffusers that produce smaller bubbles, commonly known as fine-pore diffusers, are more efficient than diffusers that produce large or coarse bubbles. Because smaller bubbles have more surface area relative to their volume, which facilitates more efficient oxygen transfer. When the bubbles are released at a greater depth, these deeper release points allow more contact time for the bubbles to diffuse oxygen into the water column as they rise to the surface (Boyd, 1998; Tucker, 2005). Placing diffuser stones above the bottom of the pond helps minimize suspension of bottom sediments. Diffuser depth also has an impression on water circulation rates within the pond.

2.10.3. Propeller-Diffuser Aerators

Propeller-Diffuser Aerators also referred as Propeller-Aspirator Pumps (Boyd and Martinson, 1984), consists of a submerged impeller-diffuser mounted on a rotating shaft contained within a hollow housing. The rotating shaft is connected to an electric motor that spins the shaft at speed upto 3,450 rpm. These are good circulators and aerators in pond but they designed more for deeper water (1-5 meter). When these are used in shallow ponds, they have a tendency to scour the basins where the water stream collides with the pond bottom, so consideration must be taken when it installed as mention by (Boyd, 1995).

2.10.4. Vertical pump aerators

Vertical pump aerators also known as impeller aerators, consists of an electric motor with either a single or dual impeller attached to the motor shaft. These aerators are manufactured in size ranges from 1kW to over 100 kW, but those used for aquaculture are rarely larger than 3Kw (Boyd, 1990). Typically, these entire unit is suspended just below the surface of the water by a float. The float must have two anchor points to keep the unit in place and prevent rotation of the unit during operation.

2.10.5. Power Take Off (PTO) -Driven aerators

Aerators powered by the PTO of farm tractors are manufactured for use in ponds where electricity is not available. They are also useful in emergency situations because of their portability. Various types of PTO-driven paddle wheel aerators are discussed by (Boyd and Watten, 1989).

2.10.6. Gravity Aerators

Gravity aerators are also known as waterfall aerators or cascades. These aerators utilize the energy released when water loses altitude to transfer oxygen. Gravity fall is the simplest way to aerate in flowing water aquaculture system if a sufficient gradient exists. Man-made gravity aerators consist of weirs, splashboards, lattices and screens. Transfer efficiencies of 1.2 - 2.3 kg O_2/kWh^{-1} are under possible standard conditions (Chesness *et al*., 1971).

2.11. Use of aerators in ponds

Aerators can increase fish and shrimp production in ponds, but there are few generally accepted guidelines on how best apply aeration in ponds. Boyd (2001, 2003), Tucker, 2005, Tucker and Robinson, 1990) highlighted the importance and functions of aeration process as follows:

-It increases pond productivity and fish growth.

-It regulates water temperature especially as this can affect dissolved oxygen (DO) of aquatic organisms.

-It is used to control thermal stratification and prevent eutrophication in fish ponds

-It reduces the concentrations of ammonia, nitrites and carbondioxide

-It increases pH level of pond water

-It increases the carrying capacity of an aquaculture system

-It reduces fish mortality

-It enhances fish reproduction systems

-It reduces level of salinity especially during time of low rainfall.

2.12. Aerator placement

Proper placement of aerator in ponds play a significant role in efficient mixing of water throughout ponds. If water mixing is important, aerators should be placed where they will improve pond water circulation patterns. For example, water circulation in large, rectangular ponds is optimized by placing paddle wheel aerators off the bank near the middle of the longer axis of the pond to direct currents across the short axis (Boyd and Watten, 1989). Another factor that influences the efficiency of an aeration system is the placement of the aerators within the pond, relative to both the type of aerator used as well as the need for aeration. All aerators provide some level of water circulation within the pond. Depending on the type of aerator, this circulation can be primarily oriented horizontally or vertically to the pond surface. If the long axis of a pond is oriented along the direction of prevailing winds, locating aerators to take advantage of wind-driven currents will help to distribute oxygenated water and will improve circulation as well as transfer efficiency. These factors will produce the most effective circulation in the pond and promote optimum water quality and also production conditions. When several aerators are used in a pond, it is better to locate the equipment so that they work with, rather than against each other in producing current. Locating several aerators in a pond should be done according to site factors such as depth, direction of prevailing winds, proximity to electrical power sources and accessibility for fueling and maintaining the equipment. Typical PTO-powered aerators, which are more commonly used for emergency use, should be located in an area where the tractor can be safely positioned and there is suitable access to the pond.

PTO-driven paddle wheel aerators are used in shallow depths and can create strong currents that erode the pond bottom and increase turbidity. The erosion can be significant enough where the aerator actually sinks into the scour hole created by the aerator, which may reduce aeration efficiency and place additional load on the tractor, aerator components and drive train. PTO-powered units should be operated in designated areas within the pond where erosion-resistant materials have been incorporated into the pond bottom. Paddle wheel and pump aspirator aerators create strong horizontal circulation currents. The angle of propeller aspirator pumps can be adjusted to change the degree of circulation in the horizontal or vertical direction. When only one of the above-referenced units is deployed, the best place to operate the unit is at the middle of the long axis of the pond with the current directed across the short axis of the pond. When multiple units are deployed they can be located in the same orientation to produce several circulation cells within the pond. Conversely, they can be positioned around the perimeter of the pond with the current directed parallel to the shoreline to create one large circulation cell in the pond (Tucker, 2005). The circulation of water around the perimeter of the pond can induce erosion around the pond perimeter and deposition of material near the pond center.

2.13. Design and performance of aerator systems in aquaculture ponds

Paddle wheel aerators are usually fabricated by fish farmers or local machine shop operators and variation in design and operation is great. Taufic and Boyd (1988) have conducted an experiment to design and study the performance of paddle wheel aerators. From the results of their study they found that Paddles with triangular cross section were more efficient than other paddle shapes. The standard oxygen transfer rate (SOTR) increased with increasing paddle depth and paddle wheel speed, while standard aeration efficiency (SAE) declined. They also noticed that for a particular depth and speed, SOTR increased as paddle wheel diameter increased. The greatest SAE of (2.96 kgO_2kWh^{-1}) was achieved for a 91cm diameter paddle wheel with triangular shape which has, operated at 77 rev/min and 12.5 cm paddle depth.

Paddle-wheel aerators are surface aeration system which can be vertical shaft or horizontal shaft that producing a large air-water interface and the transfer of oxygen from atmosphere is enhanced. Omofunmi *et al*. (2016) have developed low cost prototype paddle wheel aerator for cat fish production using locally available materials for small to medium scale fish farmers in Nigeria. They concluded that the paddle wheel aerator improved the water quality by addition of oxygen leading to appreciable increase in the fish stock density which has been a major setback of low- income fish farmer in Nigeria. The machine is effective and efficient at volume of pond water equal to or less than 2 m^3. This device is recommended for modification to perfect its functions and for scaling up for the benefit of the large scale fish industry.

The oxygen transfer rate from gas to liquid phase is dependent on various factors for a given method of aeration such as dynamic variables like speed, mixing intensity and turbulence. Geometrical parameters like size and number of blades, depth of immersion etc. and physicochemical properties of the liquid. Even though the designer or operator can fix or control some of these parameters, successful design requires the knowledge of the effect of all such parameter on re-aeration rate. Thakre *et al.* (2008) have conducted an experiment to study the effect of different configurations of mechanical aerators on oxygen transfer and aeration efficiency with respect to power consumption. The main objective of this study was to find out the variations in overall oxygen transfer coefficient (K_{La}) and aeration efficiency (AE) for different configurations of aerator by varying the parameters viz., speed of aerator, depth of immersion, blade tip angles so as to yield higher values of K_{La} and AE. For this study they have developed and fabricated different configurations of aerator such as cage rope wound rotor (CRWR), cage fin rotor (CFR), brush rotor and curved blade rotor (CBR) were tested for above mentioned parameters. From the study, they found that the curved blade rotor (CBR) emerged as a potential aerator with blade tip angle of 47°. The mathematical models were also developed for predicting the behavior of CBR with respect to K_{La} and power.

A new modified design of the paddlewheel aerator is the spiral aerator. Bhuyar *et al*. (2009) reported that, all aerators are designed to create a greater amount of contact between the air and water to enhance gas transfer. Linde (2007) stated that successful fish production depends on good oxygen management. In this aerator, number of handles fitted with cups at their two ends rotate inside the water surface in a vertical plane to effect aeration. Roy *et al*. (2017) have conducted an experiment to study the design characteristics of spiral aerator. In this study, the performance of a spiral aerator, a modified design of the paddlewheel aerator, was evaluated to determine its applicability in aquaculture ponds. The results showed that the least aeration cost is achievable when rotational speed of the spiral aerator is only 70 rpm for pond volumes up to 700 m^3 and it ranges from 120 to 220 rpm for pond volume exceeding 700 m^3.

Aquacultural research is often conducted in small ponds of 500-5000 m^2 in area and small ponds are also used in some types of commercial aquaculture. Aerators of 0.25 - 2 hp are often used in smaller ponds. Small paddle wheel aerators (1 and 2 hp) are made in Taiwan and sold worldwide for use in small ponds. These units are widely used because they are available and relatively inexpensive, but they are not very durable and their oxygen-transfer efficiency is low (Boyd and Ahmad, 1987). Moore and Boyd (1992) have conducted an experiment on design of small paddle wheel aerators. The oxygen-transfer rate and power input to the aerator shaft were determined for paddle wheel aerators of different diameters, lengths, paddle depths and rotational speeds. These data were helpful for the selection of the best design criteria among paddle wheel aerators ranges from 0.25 to 2.0 hp. These aerators also had standard aeration efficiencies. They concluded that small paddle wheel aerators made according to this design would be slightly less efficient in transferring oxygen to pond water than large paddle wheel aerators.

Eckenfelder (1956) studied the performance characteristics of numerous aeration system and he categorized them into their basic categories such as 1. Small orifice porous diffusion unit 2. Impingement or jet aerator type units 3. Mechanical aerators that entrain atmosphere oxygen by surface agitation. Swingle (1968) stated that circulation and aeration of surface water with pumps or by stirring with boat or outboard motor prevented fish kills due to phytoplankton blooms, particularly of the species *microcystis* and *anabaena*.

Moulick *et al*. (2002) first used the concept of similarity criteria in predicting the oxygen transfer performance of single-hub paddle wheel aerators, but did not consider the effect of volume of water under different dynamic conditions for oxygen transfer. As a continuation, Moulick *et al*. (2005) used the same concept of similarity criteria and considering the effect of volume of water under different dynamic conditions for oxygen transfer. They were able to formulate simulation equations for predicting aeration performance of single-hub paddle wheel aerators and also arrived at an optimum dynamic condition at which the standard aeration efficiency (SAE) is maximum. Sanjib Moulick and Mal (2009) have deliberate the performance evaluation of double-hub paddle wheel aerator at different dynamic conditions. The results showed that the oxygen transfer simulation curve for double hub paddle wheel aerator was almost matched that of a single-hub paddle wheel aerator. However, the power consumption simulation curve for double hub aerator distinctly deviated from that of a single-hub paddle wheel due to the fact that if geometric and process conditions remain the same, a double- hub paddle wheel consumes more power than a single hub. Hence, a separate power consumption simulation equation was developed for a double-hub paddle wheel aerator. The optimum dynamic condition producing maximum standard aeration efficiency was also presented along with a sample calculation.

Aerators require informations on their efficiency in oxygen transfer rate and also the total oxygen consumed in the farming system, which is composed by sediment respiration rate (SR), water respiration rate (WR) and farmed organisms respiration (Fast and Boyd, 1992). Dalla Santa and Vinatea (2007) have conducted an experiment for evaluation of respiration rates and mechanical aeration requirements in semi-intensive shrimp *Litopenaeus vannamei* culture ponds. The sediment respiration rate (SR) and the water column respiration rate (WR) were characterized using the column method, by which ponds initial and final dissolved oxygen concentrations were determined. During the study period the SR was significantly higher than WR, except for the third week of culture period. SR showed a wide variation during the experiment and the highest respiration rate occurred in the last week of culture period. Temporal aeration requirements were characterized from SR and WR data and also from the shrimp mean respiration rate described in this study.

Over the years, various types of aerators have been developed specifically to enhance the production of aquatic species. The performances of these aerators are generally compared in terms of standard aeration efficiency. However, suitability of a particular aerator at different pond sizes and water quality conditions can be determined in terms of aeration cost per unit time of operation. Kumar *et al.* (2013) have conducted an experiment to compare the standard aeration efficiency of five different aeration system such as circular stepped cascade (CSC), pooled circular stepped cascade (PCSC), 1-hp paddle wheel, 2-hp paddle wheel and propeller aspirator pump. They concluded that both CSC and PCSC aerators were found suitable for pond size less than 1000 m^3. However, for pond sizes more than 5000 m^3, one-hp paddle wheel and two-hp paddle wheel aerators were found more efficient.

Paddle wheel aerators were found to be the most efficient aerators in terms of standard aeration efficiency (1.1 to 3.0 kg O_2 /kWh) and circulation (Rappaport *et al*., 1976; Boyd and Ahmad, 1987; Lawson, 1995; Colt and Orwicz, 1991; Boyd, 1998). Roy *et al.* (2015) studied the effect of rotational speeds of spiral paddle wheel aerator on operational cost and reported that the least aeration cost is achieved at a rotational speed of the aerator was 80 rpm for pond volume up to 700 m^3.

Many types of aerators have been used in aquaculture farms for aeration purpose. Aeration is the process of bringing water and air into close contact by exposing drops or thin sheets of water to the air or by introducing small bubbles of air and letting them rise through the water. Tsadik and Kutty (1987) stated that ambient DO range produce the best fish performance, while low DO levels limit respiration, growth and other metabolic activities of fish. The aim of this study was to find out the best air distributor shapes to supply fish ponds with the enough dissolved oxygen concentration. Hatem *et al.* (2017) have conducted an experiment to study the effect of air distributor shapes on the dissolved oxygen in fish pond water. They revealed that, the best shape of air distributor was big spiral shape, because it achieved the highest bubbles free moving, distribution and diffusion on the pond and also attained significant distance from sides or walls as well as between air bubbles each other.

The effects of organic loading of intensive shrimp pond water on oxygen transfer rates and the dynamic nature of oxygen concentrations in pond water, empirical data were used to verify relationships between feeding rate, aeration rate and dissolved oxygen level. Stephen Hopkins *et al.* (1991) have studied the relationship between feeding rate, paddle wheel aeration rate and expected dawn dissolved oxygen in intensive shrimp ponds. Results indicated that dawn dissolved oxygen (mg/l) can be predicted based upon the amount of feed applied (kg/ha/day) per unit aeration (hp-day/ha). The amount of feed which can be applied with a given amount of supplemental aeration and a reasonable expectation that dawn dissolved oxygen will not be below a targeted concentration. Fast *et al*. (1988) reported that the respiration in 0.1 ha shrimp ponds having one-meter depth water, was about 0.43, 0.12 and 0-0.2 kg O_2/h for sediment, plankton and shrimp respectively.

The efficiency of oxygen transfer depends on many factors including the type, size and shape of diffusers and also the tank geometry. Kossay (2006) has conducted an experiment on analysis of oxygen transfer performance on sub-surface aeration systems. In this study, the effect of the depth of water in the tank and the extension of coverage area of diffusers on each of oxygen transfer capacity (OC), efficiency (E) and also on a percentage of oxygen absorption (δ) were tested. The results of the study showed that, both the depth of water and the extent of coverage area of diffuser had a significant effect on the tested parameters.

Aerators generally used in aquaculture ponds are operated throughout the night without regulation. Indian practices are typically semi-intensive with a reliance on mechanical aerator. Now a days spiral aerators are being extensively used for aeration of such culture. Roy *et al*. (2016) have conducted a study on the performance evaluation of spiral aerator. These experiments were conducted in a cement concrete tank of dimension 5 m × 5 m × 1.5 m. It was found that the maximum SOTR (standard oxygen transfer rate) and SAE (Standard Aeration Efficiency) of 0.622 kg O_2/h and 1.0 kg O_2/kWh were obtained at the highest and the lowest operational speeds of 240 and 70 rpm respectively.

Paddlewheel aerators are the most common mechanical aerators used in pond aquaculture today. Fast *et al.* (1999) have conducted the research to study the paddle wheel aerators oxygen transfer efficiencies at three salinities and reported that salinity significantly effect on oxygen transfer efficiencies with paddlewheel aerators. Boyd and Watten (1989) have reported that, large paddlewheels typically have a single impeller shaft with blades (paddles) spirally arranged along the shaft, while smaller Taiwanese style paddlewheels typically have two or four impellers each with six or eight inline blades on each impeller. Prior investigations demonstrated that much greater aeration efficiencies for the spiral blade design compared with other designs (Ahmad and Boyd, 1988).

Kumar and Kuloor (1970) reported that, salinity effect on SAE (Standard Aeration Efficiency) with air injection systems relates to bubble sizes and numbers. Due to differences in surface tension caused by dissolved salts, injected bubbles are more numerous and smaller in saline water compared with freshwater. This results in greater bubble surface areas and greater gas transfer across the gas–water interface.

Rogers and Fast (1986) reported that, SAE (Standard Aeration Efficiency) values increased 80% at 34% salinity compared with freshwater using paddlewheel aerator. Boyd and Daniels (1987) reported that, no difference in oxygen transfer rates using a surface agitator aerator with salinities ranging from 0 to 40 %. Ruttanagosrigit *et al.* (1991) found that, there was no effect on oxygen transfer rates at salinities ranging from 0 to 30% when paddlewheel aerators were used.

A novel type of aerator called Micro Bubble Generator (MBG) have been developed for fresh water fish farming. The Micro Bubble Generator (MBG) was run based on the principle of Venturi tube in which water was circulated through a narrowed channel so that air was sucked into the device and pushed by the flowing water to create micro-sized bubble. Budhijanto *et al*. (2017) have studied application of micro bubble generator (MBG) as low cost and high efficient aerator for sustainable fresh water fish farming. They reported that the promising potential of micro bubble generator (MBG) as affordable aerator to be applied in intensive aquaculture. Although the dissolved oxygen level did not differ significantly with the conventional aerator, MBG aerator indicated faster degradation of organic content in the water and induced faster growth of the fish as measured by their length and weight.

To improve the performance of a diffused aeration system, a series of aeration studies using various diffusers were initiated. Jia-Ming and Sheng-Ping (2003) have conducted an experiment on oxygen transfer rate in a coarse-bubble diffused aeration system. The experimental results showed that the volumetric mass-transfer coefficient of the ASCE (American Society of Civil Engineers) model and of the surface reaeration zone increase, with the airflow rate and temperature, but decreases with the water depth. The volumetric mass-transfer coefficient of the gas-bubble zone also increases with the airflow rate and water temperature, but is independent on the water depth. The saturation DO concentrations and the volumetric oxygen transfer rates under varying aeration conditions can be predicted by the two-zone model satisfactorily.

Martin and Boyd (1982) have conducted an experiment to study oxygen transfer calculations for a tractor-powered paddlewheel aerator. In this experiment standardized aeration tests were conducted for a tractor-powered paddlewheel aerator. The outcomes shows that greatest oxygen transfer coefficient (30.0 $hour^{-1}$) and oxygen transfer rate (35.1 kg of oxygen $hour^{-1}$) were obtained at 108 rpm and 54 cm paddle depth. All trials have been conducted at the rate of 108 or 128 rpm with paddle depths of 36 cm or more, had oxygen transfer coefficient and oxygen transfer rate greater than 20 $hour^{-1}$ and 20 kg of oxygen $hour^{-1}$ respectively. There was good relationship between the size and shape of spray patterns and oxygen transfer coefficients and rates.

Among sufficient aeration facilities the microporous aeration systems with advantaged energy-saving, environmental protection, easy installation, adaptability and other good characteristics are popular for aquaculture ponds. Xiangju cheng *et al.* (2016) have conducted the research to study the effect of the different shapes of air diffuser on oxygen mass transfer coefficients in microporous aeration systems. The experiments were attempted under different shapes of air diffuser rolled up by a same length of aeration tube in laboratory. The shapes were I-shape, C-shape, S-shape and Disc-shape. The results showed that the optimal aeration efficiency has achieved by I-shaped diffuser followed by C-shape and disc-shaped diffuser, the poorest efficiency obtained by S-shape.

Koch *et al.* (1975) stated that choice of an aeration system depends mainly on technical and economical aspects other than specific requirements, because artificial aeration involves high energy cost and requires large apparatus. They concluded that atmospheric oxygen diffusion is not sufficient to meet the oxygen demand of biota in intensive fish culture units. Chesness *et al*. (1971) have conducted experiment on six gravity flow aerator models in the laboratory and found that corrugated plane and riser models were better. Their effectiveness in the field was equal or even better than that observed in the laboratory. Mikheev (1973) described the various air-lift pumps design and mode of operation to aerate cage type fish farms and found that these aeration systems were economically feasible. Busch *et al*. (1974) opined that for large scale operation paddle wheel surface aerators are the most suitable. Their results were based on fish production and consumption of power. Castro *et al.* (1975) found that air-lift pumps of shorter length and smaller diameter involved in mariculture operation were better compared to those used for freshwater aquaculture.

The paddlewheel aerator was developed by catfish producers to meet their needs for a durable, mobile aerator that could provide sufficient aeration for emergency situations in large commercial ponds. Busch *et al*. (1984) carried out an experiment on an evaluation of three paddlewheel aerators used for emergency aeration of channel catfish ponds. They determined oxygen transfer rate, power requirement and fuel consumption. Results of the observation showed that power requirement of the tractor-powered unit was directly related to the diameter of the paddlewheel drum and the paddle immersion depth. Oxygen transfer rate increased linearly with the power requirement. The largest paddle wheel aerator operated at the maximum paddle depth, produced the highest oxygen transfer rate.

Rappaport *et al*. (1976) have carried out an experiment on five different aeration devices for oxygenation of pond water they are as follows (i). Permeable plastic pipes (ii).Venturi type injector (iii). Blower installed close to the bottom (iv). Floating aerator and (v). Two sizes of Japanese water mills. They found that the aerators which pumped bottom water and sprayed it at surface were most efficient than the other which injected the air into the pond water, while the first three methods were less expensive. A study was carried out on the performance characteristics of pond aeration devices to select an effective system for use in the culture of *Macrobrachium rosenbergii* by (Mitchell and Kirby, 1976). They found that the Air-O-Lator aerator was the most suitable from oxygen transfer point of view.

Aeration is widely used in fish culture. Standard tests of aerator performance have been developed by the wastewater-treatment industry. Equations that adapt standard performance characteristics to nonstandard field conditions have been developed for wastewater, but their applicability to aquacultural facilities has not been evaluated. James *et al*. (1983) have carried out the work to find out correction factors for calculating oxygen-transfer rates of pond aerators. Correction factors for the oxygen-transfer coefficient (α) and concentration of oxygen at saturation (β) were determined for waters from 43 fish-culture system. The values of α ranged from 0.66-1.07, where as β factor ranged from 0.92-1.00. The magnitudes of α and β were not correlated with turbidity, specific conductance, chemical oxygen demand or chlorophyll-a concentration. A table of factors for estimating aerator performance under pond conditions was developed. Gray *et al*. (2011) have carried out an experiment on aeration system design for energy savings and results showed that successful operation of the system depends on the successful operating of all the components of the system. This study describes that a well-designed aeration system can save up to 25 to 40% of energy consumption.

Ferard and Junk (1974) have deliberate the water quality requirements of fishes with a view to understand the concentration in fish culture. They also studied oxygenation as a means of water purification and found that U-tube aerators were better than air lift pumps. Boyd and Martinson (1984) have evaluated the performance of propeller-aspirator-pump aerators and stated that small aerators were widely used in aquaculture to improve dissolved oxygen content in the pond water. A comparative studies of mechanical aeration and oxygen sparging to oxygenate a trout pond was conducted by Berglind (1983). The results of his study revealed the advantage of injecting oxygen into the pond water.

Aeration with multiple paddle wheel aerators prevented thermal stratification and oxygen depletion during night hours. Knoesche (1978) has compared the various aeration systems based on test performance and observed that the points to be considered in the evaluation of aeration plants are the final concentration reached the oxygen input and the oxygen yield. Wieting *et al*. (1978) have compared the Venturi-aeration-apparatus with other aeration systems for use in aquaculture. Kranawettreiser *et al*. (1978) have used the hydro-pneumatic aerator for intensive fish farming. They found that it was much useful for fish breeding units in warm water.

Ben-Yaakov (1979) has designed and operated a dissolved oxygen analyser. He discussed various aspects of dissolved oxygen management and problems encounterd in the process. Paddle wheel aerator powered by a tractor was found to be the most efficient for emergency aeration, while spray type surface aerators failed to increase dissolved oxygen concentrations appreciably (Boyd and Tucker, 1979). Work of Reiehle (1979) has revealed that stocking density can be doubled by artificial aeration with liquid oxygen. Kils (1979) has built a special net cage aerator for use in cages. He pointed out the factors affecting oxygen level in net cages and problems of aeration.

Busch (1980) has designed and tested a new paddle wheel aerator. He observed that stirring of pond water by paddle wheel instead of splashing, bubbling or spraying caused better circulation. Castro and Zielinski (1980) reported that air-lift pump is the most commonly used device in many mariculture systems, which serve dual purpose of circulation and aeration. According to them, its low initial cost and simplicity of operation makes it more feasible, inspite of low efficiency. Apud and Camacho (1980) have studied the effect of water movement and air-lift aeration on the survival and growth of *Penaeus monodon* and opined that the high survival rate obtained with aeration justifies the need for aeration.

Kumar *et al*. (2010) have conducted an experiment on performance evaluation of propeller-aspirator-pump aerator. They study the effects of positional angle of propeller shaft (α), submergence depth and rotational speed of shaft on standard aeration efficiency (SAE) of a propeller-aspirator-pump aerator. The results showed that standard aeration efficiency (SAE) becomes maximum at α=75°. In a similar way, keeping the geometric condition constant (α=75°), aeration experiments were further conducted at different rotational speeds of propeller shaft, N (1420, 1775, 2130, 2485 and 2840 rpm) and different values of submergence depth, d (140, 220, 300, 380 and 460mm) to evaluate the effect of dynamic conditions on aeration characteristics. Finally, maximum standard aeration efficiency (SAE) of 0.42kg O_2/kWh was obtained at positional angle of 75°, rotational speed of 2840 rpm and submergence depth of 140 mm of propeller shaft.

Jayraj *et al*. (2017) have conducted an experiment on design characteristics of submersible aerator. Aeration experiments were conducted on original and modified submersible aerator to evaluate its performance and to optimize the aeration efficiency. The angular position of the propeller (α) and submergence depth of the propeller (d) were varied to study their effects on standard aeration efficiency (SAE). Pre-performance evaluation of the original design without having a provision to vary (α) and (d) was done and resulted in SAE of 0.320 kg O_2/ kWh. The aerator was modified to have a provision to change (α) and (d) of the aerator. To evaluate the optimum (α), experiments were conducted at different α: 0°, 15°, 30°, 45°, 60°, 75°, keeping the rotational speed (N) = 2900 rpm and d = 450 mm as constants. The optimized α was 75°. In the same way to optimize d, experiments were conducted at different d: 300, 350, 400, 450, 500, 550, and 600 mm, keeping N = 2900 rpm and α = 75° as constants. The optimized d was 350 mm. Finally the optimized value of SAE of 0.616 kg O_2/kWh was achieved at α = 75° and d = 350 mm. The percentage increase in efficiency after modification was 92.50 %.

Fine bubbles are a key component in improving the performance of gas-liquid reactors, particularly in situations where reactions are mass transfer limited. Hanotu *et al.* (2017) have conducted an experiment on aerator design for microbubble generation. A new aerator suitable for microbubble generation by fluidic oscillation has been designed and tested with the view of getting a uniform bubble distribution across the aerator. Microbubbles generated from various membrane pore sizes and oscillation frequencies were characterized for this aerator to determine the optimum operating parameters. The result shows that the average bubble size from this new design under oscillatory flow was found approximately 2-3 times the membrane pore size. This outcome has a great potential to promote the efficiency of multiphase reactors where mass transfer plays a key role.

Petrille and Boyd (1984) have conducted an experiment for comparison of oxygen-transfer rates and water-circulating capabilities of emergency aerators for fish ponds. Oxygen-transfer rates for four tractor powered emergency aerators tested in a 820 m^3 pond was: blower-fan aerator, 12.2 kg O_2/h; Crisafulli (pump and sprayer), 12.3 kg O_2/h; Airmaster aerator (centrifugal pump and sprayer), 21.3 kg O_2/h; paddlewheel aerator, 26.3 kg O_2/h. Time required for aerators to homogeneously mix salt in a 6000 m^3 pond was: blower-fan aerator, 96 min; Crisafulli (pump and sprayer), 94 min; paddlewheel aerator, 53 min; and Airmaster aerator, 38 min. The Airmaster aerator and the paddlewheel aerator did not differ in their abilities to transfer oxygen and circulate pond water; they were both superior to the blower-fan aerator and the Crisafulli (pump and sprayer).

MATERIALS AND METHODS

III. MATERIALS AND METHODS

Oxygenation is the most important function of aerators. Aerators influence the rate of oxygen transfer from air to water by increasing turbulences and surface area of water in contact with air. The amount of oxygen entering from the air to water increases with greater surface area.

The present research was conducted at the Research and Instructional Fish Farm of the College of Fisheries, Mangaluru. Three uniform square shaped cement ponds of the size (5 × 5 × 1 m) were selected for conducting the experiment. Four aerator designs namely i) Three tier perforated tray aerator ii) Vertical perforated cylindrical aerator iii) Rotating wheel aerator and iv) Cascading wooden plank aerator were planned, designed and fabricated. Each aerator designs were fabricated in triplicate. These aerators were used to check their oxygenating efficiency. These aerators were also used to find out the oxygen dissolution in the pond water during day and night time.

3.1. Materials

3.1.1. Wood

Wood is used to fabricate the cascading wooden plank aerator and rotating wheel aerator design. Wood is also used to fabricate the stands to keep the aerator designs properly.

3.1.2. Perforated sheet

Two GI (Galvanized Iron) perforated sheets were purchased with a dimension of 3 × 8 feet. Each sheet consist of 6 mm diameter holes and space between the two consecutive holes is 2 mm.

3.1.3. Fabrication of aerators

3.1.3.1. Three tier perforated tray aerator

Using the GI (Galvanized Iron) perforated sheets, three tier perforated tray aerator designs with a dimension of 85 × 85 × 5 cm were fabricated (Fig. 1 and Plate 1and 2).

3.1.3.2. Cascading wooden plank aerator

Cascading wooden plank aerator design was made with wooden plank of size 95 × 85 × 2 cm. The rectangular shaped wooden pieces of size 85 × 2 × 7 cm were inclined in such a manner to create a cascading effect of flow of water. The whole set up was kept on a wooden stand as shown in Fig. 2 and Plate 3 and 4.

3.1.3.3. Rotating wheel aerator

Rotating wheel aerator design was made with wooden planks of size 40 × 30 × 2 cm. Four wooden planks were fitted to GI (Galvanized Iron) pipe of diameter 1.25 cm and length of 80 cm. The two ends of the GI (Galvanized Iron) pipe was fitted with bearings for easy rotation of wooden planks. The whole set up was kept on a wooden stand as shown in Fig. 3 and Plate 5 and 6.

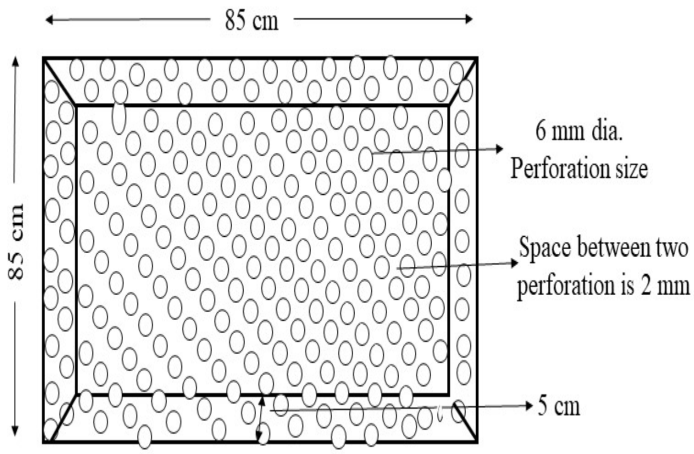

Fig. 1. Schematic diagram of perforated tray

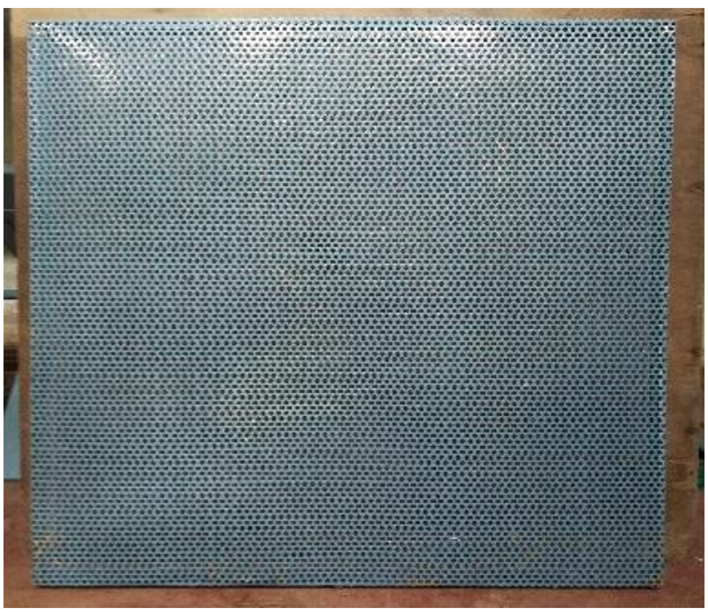

Plate 1. Perforated tray aerator design

Plate 2. Three tier perforated tray aerator

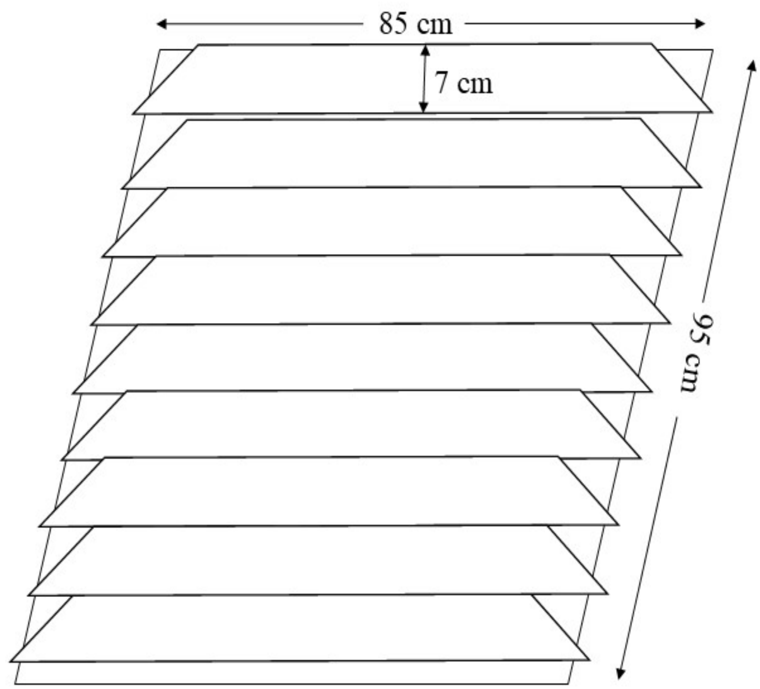

Fig. 2. Schematic diagram of cascading wooden plank

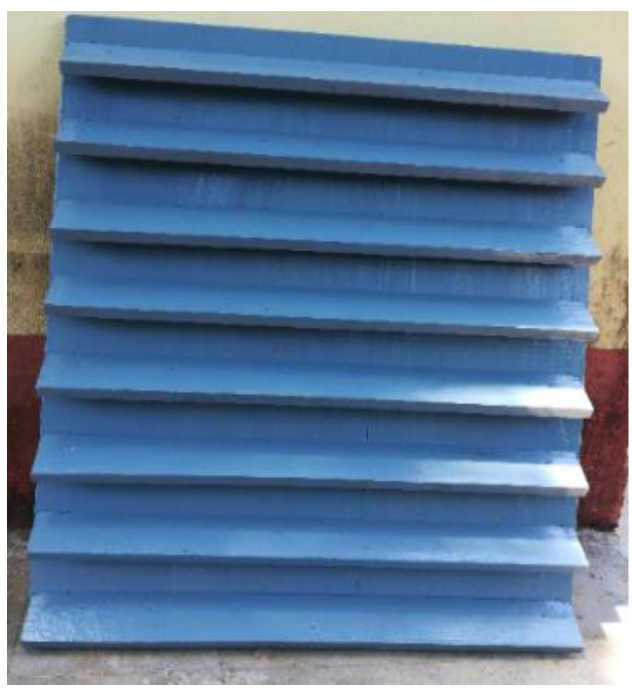

Plate 3. Cascading wooden plank

Plate 4. Cascading wooden plank aerator

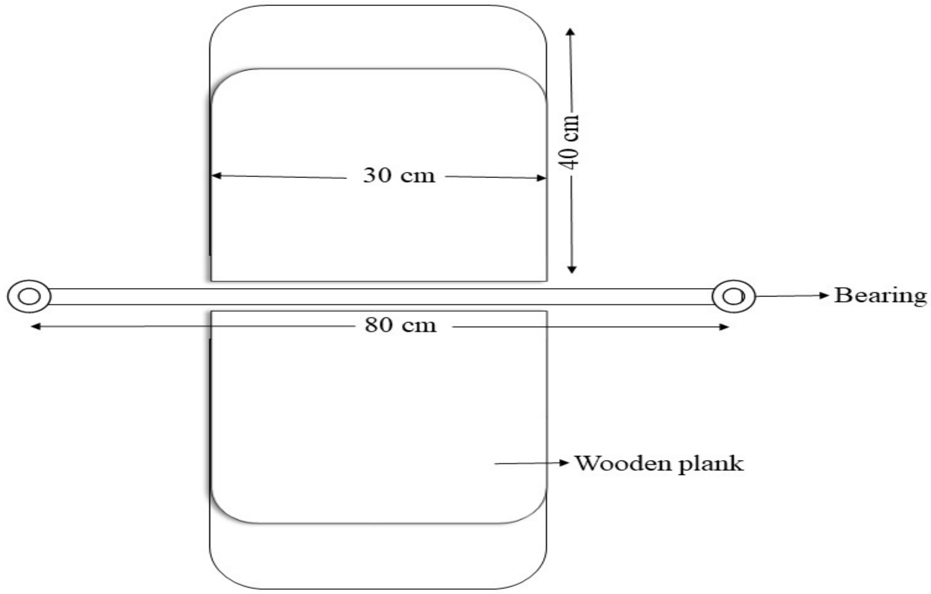

Fig. 3. Schematic diagram of rotating wheel

Plate 5. Rotating wheel aerator

Plate 6. Rotating wheel aerator

3.1.3.4. Vertical perforated cylindrical aerator

Vertical perforated cylindrical aerator (Fig.4 and Plate7) is made from a perforated Galvanized Iron (GI) sheet for a height of 38 cm and 11 cm diameter. Bottom of the aerator model is connected to the water supply pipe with the help of elbow and the other end of the aerator is closed with a sheet.

All the above aerator designs were fabricated in triplicate.

3.1.4. Wooden stand

To keep all these aerator designs properly, a stand was made with wooden size of dimension 7 × 7 cm for a length and width of 85 cm and height 135 cm (Fig.5 and Plate 8).

3.1.5. Water supply pipes

The main water supply pipe of 3.75 cm diameter was provided between pump house and ponds. The secondary water supply pipe line was connected to this main line which is having a diameter of 1.25 cm. Shower of dimension 30 × 30 cm was fitted to this secondary pipe line and connected to each and every pond separately in such a way that water has to fall on the top of the aerators.

3.1.6. Working mechanism of aerators

(a) Three tier perforated tray aerator

The water falling from the shower, has been made to fall on the top of perforated tray and it passes through pore of each perforated tray before falling into the pond water. When it

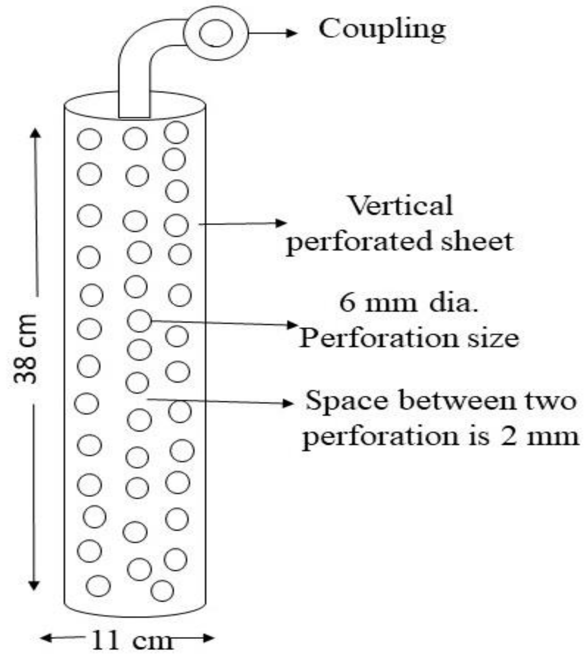

Fig. 4. Schematic diagram of vertical perforated cylindrical aerator

Plate 7. Vertical perforated cylindrical aerator

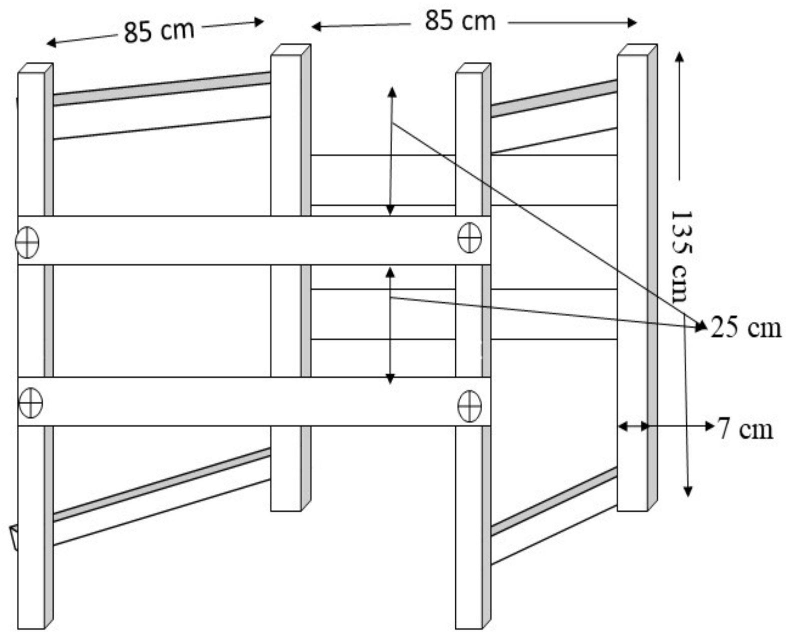

Fig. 5. Schematic diagram of wooden frame

Plate 8. Wooden stand

passes through the pores of these trays, it splits into minute particles and observe the oxygen content present in the atmosphere before reaches the pond water.

(b) Cascading wooden plank aerator

The water is allowed to fall on the upper portion of the aerator and flows towards down side. During this process water tumble in the form of thin sheet and splits into minute particles. These minute particles obserb the oxygen present in the atmosphere before falling into the pond water.

(c) Rotating wheel aerator

Water from the shower falls on the rotating wheel, which makes the wheel to rotate due to the force generated by the water. Due to this process wheels gets rotated and the water splits into small particles which interacts with air present in the atmosphere before reaches the pond water and gets aerated.

(d) Vertical perforated cylindrical aerator

The water supplied from the pipe, which passes through the bottom of the aerator and flows out through the pores of the aerator. During this process the water splits into minute particles and interacts with air presents in the atmosphere and gets aerated.

3.1.7. Shower

The shower is made up of a sheet which is perforated into small holes, size of the shower is 30 × 30 cm.

3.1.8. Experimental tanks for testing the efficiency of aerators

Three experimental tanks (Plate 9) with an inner dimension of 5 × 5 × 1 m (without soil base) located at the Research and Instructional Fish Farm of College of Fisheries, Mangaluru were selected to carry out the research work. These tanks were initially drained completely and cleaned neatly the sides and bottom of the tank. These tanks were filled with fresh water up to the level of 0.5 m depth. One side of the tank is provided with an outlet for draining out the water whenever required.

3.1.9. Dissolved oxygen meter

Dissolved Oxygen meter (Make: Aqua Read) was used to measure the DO concentration of the pond water during the experiments (Plate 10). The temperature was also measured along with the DO readings by using the thermometer attached to the DO meter. This DO meter works on the polarographic principle.

3.2. Aerator performance tests

There are many types of mechanical aerating devices are available in the market. These devices are either electrically or mechanically operated are available in a broad range of sizes. Because of confusing array of data in the literature describing aerator performance, commercially manufactured aerating devices are usually evaluated under a rigid set of standard conditions to determine their ability of transfer oxygen. These tests are referred as standard tests or clean water tests. The results are normally included in the manufactures promotional literature and it is the best way to compare two or more manufactures aerators under identical conditions.

Plate 9. Experimental tanks

Plate 10. Dissolved oxygen meter

3.2.1. Aerator efficiency

There are two basic types of aerator performance tests they are

(i)Steady-State test (ii) Unsteady-State test

Steady-State test is conducted by mounting an aerator in a stream of water and measuring flow volume and DO concentration before and after aeration. The difference in the mass of DO between the inflow and out flow represents the mass of oxygen transferred to the water by the aerator (Colt and Orwicz, 1991)

3.2.2. Unsteady-state test procedure

Standard test for aerators are conducted in basins of clean tap water at standard temperature and pressure (20 ^{0}C and 760 mm Hg). Some basins are large and can be used to test large aerators (Colt and Orwicz, 1991). Basins are typically made up of concrete or cinder block. The water is first deoxygenated using a sodium sulfite (Na_2SO_3) solution along with cobalt chloride ($CoCl_2$ $6H_2O$) as a catalyst (APHA, 1980). The change in DO concentration is measured as the water is reoxygenated with the aerator being evaluated. This procedure is termed as unsteady-state testing since the amount of oxygen transferred and the DO concentration change during the test.

3.2.3. Sampling stations

Two sampling points were taken in the test basin. Sampling points are recommended at several depths (near the surface, bottom and at mid depth) within the basin. The sampling points should be located away from the walls and floor of the tank. A greater number of sampling points may be needed for complex aeration system (ASCE 1983).

For deoxygenating the tank water 7.88 mg/l of sodium sulfite (Na_2SO_3) was used to remove 1.0 mg/l of oxygen. The cobalt chloride as a concentration of 0.25 mg/l was used as a catalyst.

Chemical slurries were first made by mixing the respective chemical with small amounts of tap water. The chemical slurries are mixed until the tank water DO drops to below 0.5 mg/l. The cobalt chloride catalyst is added to the tank water first and mixed the pond water manually for a period of 30 minutes to ensure complete mixing. The sodium sulfite solution is then splashed manually into the tank and it was mixed thoroughly. After 20-30 minutes of mixing the DO of the tank water was measured and ensured to be less than 0.5 mg/l. The aerator is turned on to increase DO concentration of the tank water. Dissolved oxygen readings are then taken simultaneously at timed intervals (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 120, 150 and 180 minutes) while the DO increases to at least 90 % saturation.

The DO deficit is computed for each time that DO was measured during reaeration

$$OD = DO_s - DO_m$$

Where,

OD = Oxygen deficit

DO_s = DO concentration at saturation (mg/l)

DO_m = Measured DO concentration (mg/l)

The natural logarithms of DO deficits (Y) are plotted versus the time of aeration (X); the line of best fit is computed with regression analysis. The oxygen transfer coefficient is computed using the above graph at points representing 10 % and 70 % oxygen saturation (Boyd and Watten 1989) as follows

$$(K_L\,a)_T = \frac{\ln(OD_{10}) - \ln(OD_{70})}{(t_{70} - t_{10})/60}$$

Where,

$(K_L\,a)_T$ = Overall oxygen-transfer coefficient (hr^{-1}) at temperature T

ln = Natural logarithm

OD_{10} = Oxygen deficit at 10 % saturation (mg/l)

OD_{70} = Oxygen deficit at 70 % saturation (mg/l)

t_{10}= Time taken for dissolved oxygen concentration to reach 10 % saturation (min.)

t_{70} = Time taken for dissolved oxygen concentration to reach 70 % saturation (min.)

The oxygen-transfer coefficient is adjusted to 20 ^{0}C with the following equation

$$K_L a_{20} = K_L a_T \div 1.024^{T - 20}$$

Where,

$K_L a_{20}$ = Overall oxygen-transfer coefficient at 20°C (hour $^{-1}$)

$K_L a_T$ = Overall oxygen-transfer coefficient at t °C (hour $^{-1}$) and

T = Test water temperature (°C).

3.2.4. Standard Oxygen Transfer Rate (SOTR)

The SOTR (Standard Oxygen Transfer Rate) is the amount of oxygen that an aerator will transfer to water per hour under standard conditions. Standard conditions are 0 mg/l DO, 20 ^{0}C temperature and clean water. The overall oxygen transfer coefficient is used to estimate the standard oxygen transfer rate for an aerator.

$$SOTR = (K_L a_{20}) (Cs_{20}) (V) (10^{-3})$$

Where,

SOTR = Standard Oxygen-Transfer Rate (kg oxygen h $^{-1}$)

$K_L a_{20}$ = Overall oxygen transfer coefficient

Cs_{20} = DO concentration at saturation and 20 ^{0}C (gm $^{-3}$ which equals mg/l)

V = Tank volume (m^3) and

* 10 $^{-3}$ is used to convert g to kg.

3.3. Influence of aerators on oxygen dissolution in pond water

To find out the dissolution of oxygen into pond water experiments have been carried out with and without using aerators (above mentioned) during day and night time. During day time initial temperature and dissolved oxygen concentration were measured, then the aerators are turned on. The dissolved oxygen concentration were measured simultaneously at timed intervals of (0, 30, 60, 90, 120, 150, 180 and 210 minutes). The same procedure was also followed in the evening time to find out the dissolution of oxygen into the pond water.

3.4. Statistical analysis

The data obtained from this research work were analysed statistically using Microsoft Excel, 2016. The linear regression was used to determine the slope of the K_La value of aerators Microsoft corporation, WA.

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The dissolved oxygen concentration is a major factor that influence the survival and growth of aquatic organisms in culture ponds. During the past decade, pond aeration systems have been developed which will sustain large quantities of fish and invertebrate biomass. Aeration-performance testing has been important in selecting design features to provide cost-effective yet efficient aquaculture pond aeration. Recent studies suggest that the use of heavy aeration to provide the greatest possible production is less profitable than moderate aeration to improve water quality and enhance feed conversion efficiency. With this back ground experiments have been carried out in three similar shaped and sized ponds located at Research and Instructional Fish Farm.

4.1. Without using aerator (Pond W_1)

In the present study, initial pond water temperature of 27 °C was observed. The pond water was initially deoxygenated and DO content measured was 0.43 mg/l. Without using the aerator the pond water DO was measured after three hours and it was 4.20 mg/l. The DO level increased slowly until it reached the final value. Increase in DO concentration in pond water was presented in the table 1and graphically depicted in Fig.6.

The overall oxygen-transfer coefficient ($K_L\ a_T$) and Standard Oxygen Transfer Rate (SOTR) obtained were 0.252 h^{-1} and 0.024 kg O_2/h respectively.

4.2. Without using aerator (Pond W_2)

In the pond W_2 the DO content measured during the study period ranged from 0.43 mg/l to 4.15 mg/l. The higher value of DO was measured after three hours and minimum DO was noticed in the beginning of the experiment. In the beginning of the experiment the DO concentration rises rapidly, later on increased gradually. Increase in DO concentration in pond water was given in the table 1 and shown graphically in Fig.7.

4.3. Without using aerator (Pond W_3)

The pond water deoxygenated initially and measured value was 0.50 mg/l, finally it reached 4.16 mg/l after three hours without using aerator. Initially DO concentration of pond water increased rapidly and increased slowly up to the end of the experiment. Increase of DO concentration in pond water was shown in the table 1 and plotted graphically in Fig.8.

The overall oxygen-transfer coefficient ($K_L\ a_T$) reached upto 0.210 h^{-1} and Standard Oxygen Transfer Rate reached upto 0.020 kg O_2/h respectively.

The observed values of deficit of oxygen versus time for all three ponds without using aerators are depicted graphically in Fig.9. From the graph it was observed that the pond W_1 shows better ($K_L\ a_T$) and SOTR value followed by W_2 and W_3 ponds.

4.4. Vertical perforated cylindrical aerator (Pond V_1)

The water temperature was measured in the beginning of the experiment and it was 28 °C in all the three ponds. The pond water deoxygenated and DO of 0.33 mg/l was recorded initially and lastly it reaches to 8.07 mg/l after three hours of using vertical perforated cylindrical aerator. Primarily DO concentration of pond water increased rapidly and gradually increased up to the final stage of the experiment. Rise in DO concentration in pond water was recorded in the table 2 and shown graphically in Fig.10.

Table 1. Increase of dissolved oxygen content in the ponds water without using aerator

Time (Min)	Pond (W_1) DO measured (mg/l) (Cm)			Pond (W_1) DO deficit (mg/l) (Cs-Cm)	Pond (W_1) ln DO deficit (mg/l)	Pond (W_2) DO measured (mg/l) (Cm)			Pond (W_2) DO deficit (mg/l) (Cs-Cm)	Pond (W_2) ln DO deficit (mg/l)	Pond (W_3) DO measured (mg/l) (Cm)			Pond (W_3) DO deficit (mg/l) (Cs-Cm)	Pond (W_3) ln DO deficit (mg/l)
	S_1	S_2	Avg.			S_1	S_2	Avg.			S_1	S_2	Avg.		
0	0.41	0.45	0.43	7.52	2.01	0.49	0.38	0.43	7.52	2.01	0.51	0.49	0.50	7.45	2.0
10	0.76	0.88	0.82	7.13	1.96	0.66	1.21	0.93	7.02	1.94	0.86	0.97	0.91	7.04	1.95
20	1.18	1.23	1.20	6.75	1.9	1.15	1.21	1.18	6.77	1.91	1.23	1.18	1.20	6.75	1.90
30	1.25	1.31	1.28	6.67	1.89	1.27	1.59	1.43	6.52	1.87	1.37	1.29	1.33	6.62	1.89
40	1.69	1.62	1.65	6.30	1.84	1.47	1.59	1.53	6.42	1.85	1.59	1.69	1.64	6.31	1.84
50	1.77	1.69	1.73	6.22	1.82	1.63	1.75	1.69	6.26	1.83	1.81	1.73	1.77	6.18	1.82
60	2.15	1.90	2.02	5.93	1.78	2.20	2.03	2.11	5.84	1.76	1.83	1.99	1.91	6.04	1.79
70	2.20	2.35	2.27	5.68	1.73	2.37	2.25	2.31	5.64	1.72	2.05	2.17	2.11	5.84	1.76
80	2.53	2.41	2.47	5.48	1.7	2.53	2.57	2.55	5.40	1.68	2.55	2.75	2.65	5.30	1.66
90	2.85	3.05	2.95	5.00	1.6	2.83	2.78	2.80	5.15	1.63	2.99	3.03	3.01	4.94	1.59
120	3.73	3.48	3.60	4.35	1.47	3.73	3.48	3.60	4.36	1.47	3.17	3.06	3.11	4.84	1.57
150	4.15	4.20	4.17	3.78	1.32	4.09	4.18	4.13	3.83	1.34	3.24	3.54	3.39	4.56	1.51
180	4.20	4.21	4.20	3.75	1.32	4.13	4.18	4.15	3.80	1.33	4.05	4.28	4.16	3.79	1.33

Source: Colt (1984) **Cs = 7.95** for a temperature of 27 °C and standard atmospheric pressure.

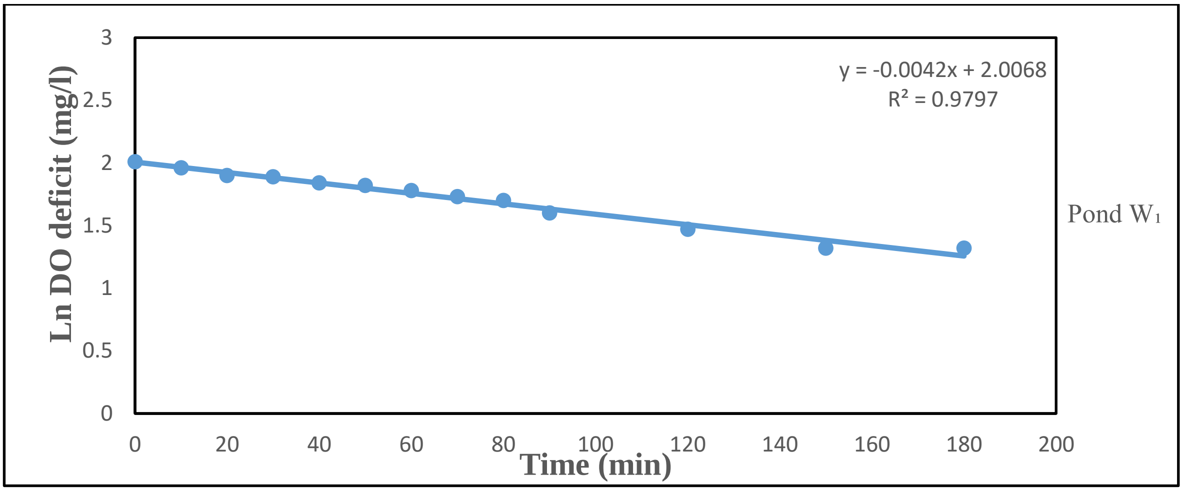

Fig. 6. Relationship between Ln DO deficit and time (Without using aerator)

Without operation of aerator the obtained DO deficit values was plotted (in log scale) versus time as straight line (Fig. 6) with this negative slope was obtained. The slope of the line gave the K_La value of the aerator at the water temperature of 27 °C.

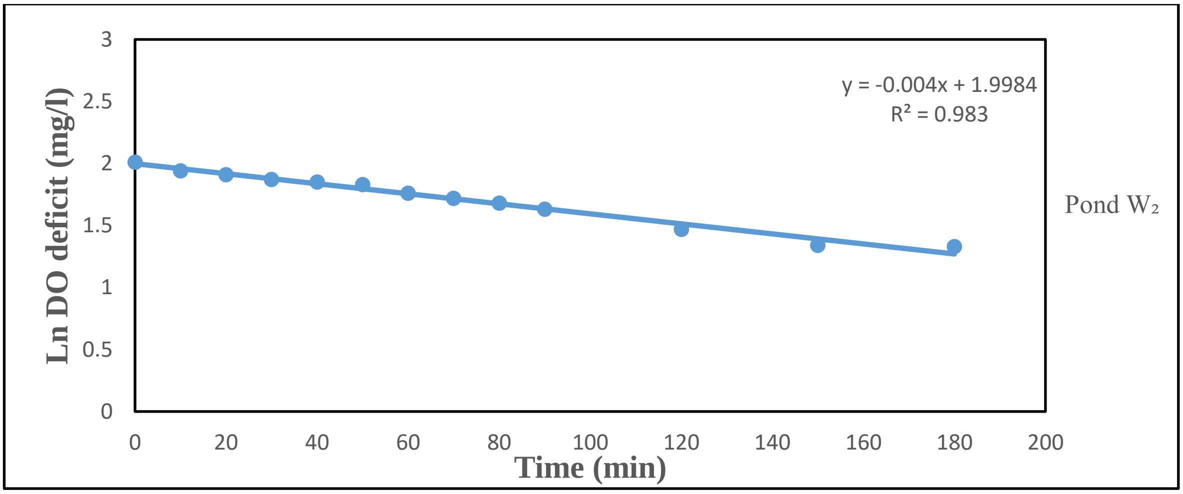

Fig. 7. Relationship between Ln DO deficit and time (Without using aerator)

The DO deficit values (in log scale) of pond water without operation aerator was plotted versus time as straight line (Fig. 7). Using this graph slope was calculated. The slope of the line gave the K_La value of the aerator at the water temperature of 27 °C.

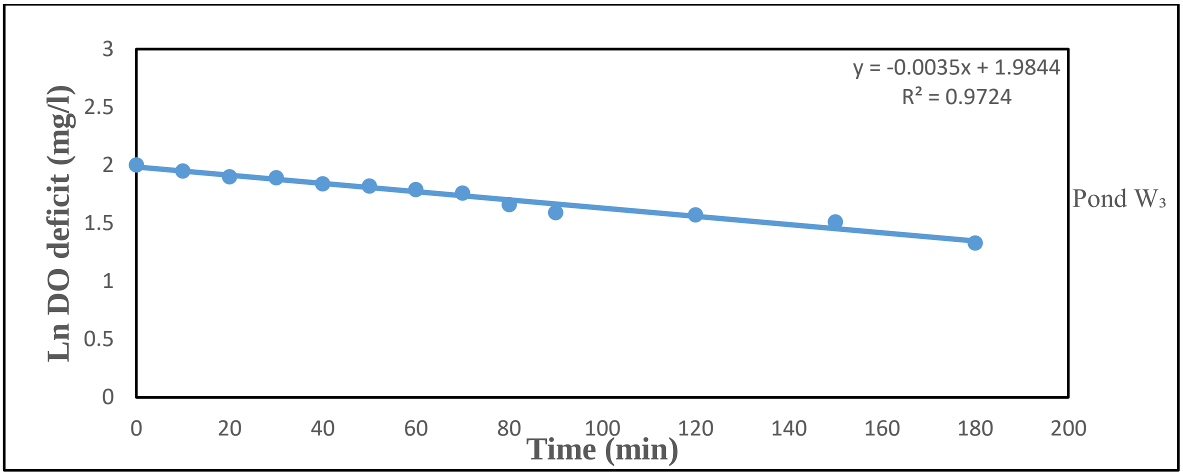

Fig. 8. Relationship between Ln DO deficit and time (Without using aerator)

The DO deficit values (in log scale) without operation of aerator was plotted versus time as straight line (Fig. 8). The slope of the line gave the K_La value of the aerator at the water temperature of 27 °C.

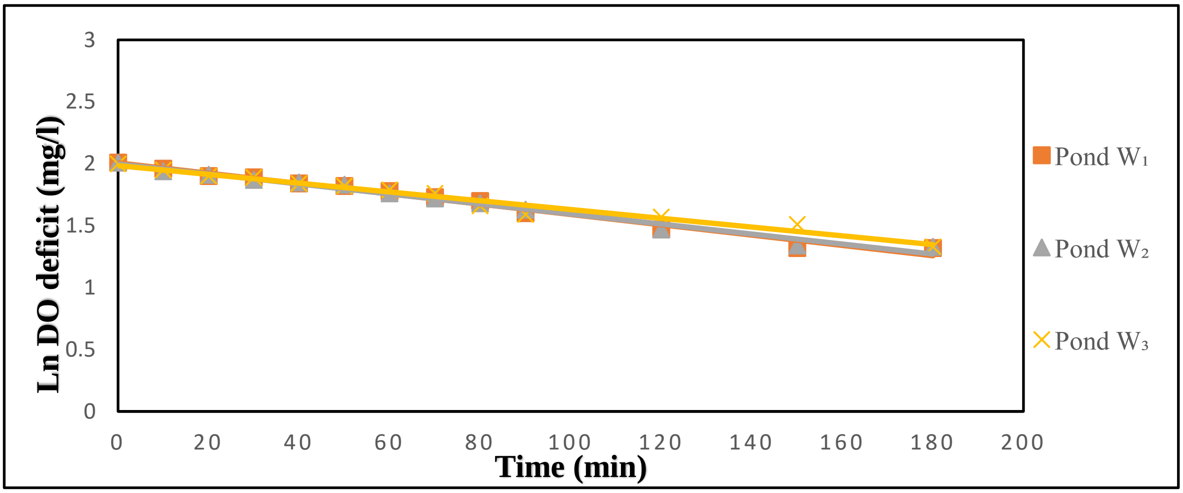

Fig. 9. Comparison of Ln DO deficit and time (Without using aerators)

The overall oxygen-transfer coefficient ($K_L a_T$) and Standard Oxygen Transfer Rate (SOTR) were recorded as 1.788 h^{-1} and 0.167 kg O_2/h respectively.

4.5. Vertical perforated cylindrical aerator (Pond V_2)

The pond water was initially deoxygenated and DO content observed was 0.10 mg/l. Using the vertical perforated cylindrical aerator the pond water was re-oxygenated, the measured DO content was 7.76 mg/l. At the beginning, the DO level of the pond water increased rapidly for a shorter period and then increased gently until it reached the final value. Increase in DO concentration in pond water is recorded in the table 2 and represented graphically in Fig.11.

The overall oxygen-transfer coefficient ($K_L a_T$) and Standard Oxygen Transfer Rate were 1.602h^{-1} and 0.150 kg O_2/h respectively.

4.6. Vertical perforated cylindrical aerator (Pond V_3)

The DO content of pond V_3 was measured during the study period it ranged from 0.18 mg/l to 7.97 mg/l. The higher value of DO measured after three hours of duration and least DO was noticed in the beginning of the experiment. After the aerator turned on the DO concentration increases rapidly, later on increased slowly. Change in DO concentration of pond water was presented in the table 2 and drawn graphically in Fig.12.

The overall oxygen-transfer coefficient ($K_L a_T$) and Standard Oxygen Transfer Rate (SOTR) were calculated using the formula as 1.560 h^{-1} and 0.146 kg O_2/h respectively.

The experimental values of Ln DO deficit versus time for all three ponds using vertical perforated cylindrical aerators are portrayed graphically in Fig.13. From the graph it was

Table 2. Increase of dissolved oxygen content in the ponds water using vertical perforated cylindrical aerator

Time (Min)	Pond (V_1)					Pond (V_2)					Pond (V_3)				
	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)
	S_1	S_2	Avg.			S_1	S_2	Avg.			S_1	S_2	Avg.		
0	0.30	0.37	0.33	7.48	2.01	0	0.10	0.10	7.71	2.04	0.37	0	0.18	7.63	2.03
10	1.83	1.88	1.85	5.96	1.78	1.65	1.73	1.69	6.12	1.81	1.88	1.65	1.76	6.05	1.80
20	3.97	3.30	3.63	4.18	1.43	2.98	3.20	3.09	4.72	1.55	3.30	2.98	3.14	4.67	1.54
30	4.12	5.56	4.84	2.97	1.08	3.65	4.92	4.28	3.53	1.26	5.56	3.65	4.60	3.21	1.16
40	4.68	5.89	5.28	2.53	0.92	5.15	5.49	5.32	2.49	0.91	5.89	5.15	5.52	2.29	0.82
50	5.18	5.89	5.53	2.28	0.82	5.33	5.81	5.57	2.24	0.80	5.89	5.33	5.61	2.20	0.78
60	5.67	5.77	5.72	2.09	0.73	5.71	5.51	5.61	2.20	0.78	5.77	5.71	5.74	2.07	0.72
70	6.02	6.47	6.24	1.57	0.45	6.02	6.28	6.15	1.66	0.50	6.47	6.02	6.24	1.57	0.45
80	6.51	6.79	6.65	1.16	0.14	6.53	6.67	6.60	1.21	0.19	6.79	6.53	6.66	1.15	0.13
90	6.86	6.96	6.91	0.90	-0.1	6.79	6.92	6.85	0.96	-0.04	6.96	6.79	6.87	0.94	-0.06
120	7.45	7.55	7.50	0.31	-1.17	7.55	7.20	7.37	0.44	-0.82	7.55	7.55	7.55	0.26	-1.34
150	7.80	7.73	7.76	0.05	-2.99	7.60	7.72	7.66	0.15	-1.89	7.73	7.60	7.66	0.15	-1.89
180	8.12	8.03	8.07	-	-	7.92	7.61	7.76	0.05	-2.99	8.03	7.92	7.97	-	-

Source: Colt (1984) **Cs = 7.81** for a temperature of 28 °C and standard atmospheric pressure.

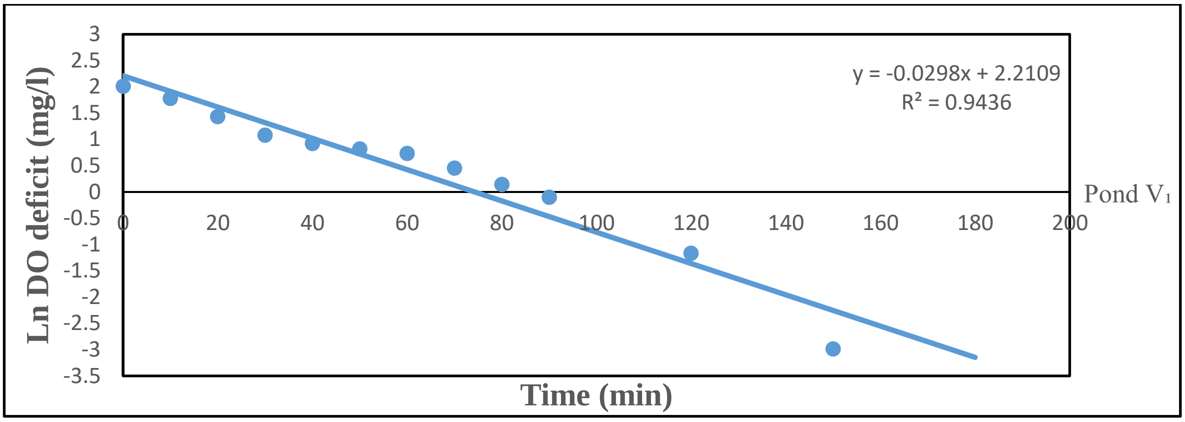

Fig. 10. Relationship between Ln DO deficit and time (Vertical perforated cylindrical aerator)

Changes in the DO deficit values (in log scale) of vertical perforated cylindrical aerator was plotted versus time as straight line in the (Fig. 10). The K_La value of the aerator at the water temperature of 28 °C was calculated using the slope of the graph.

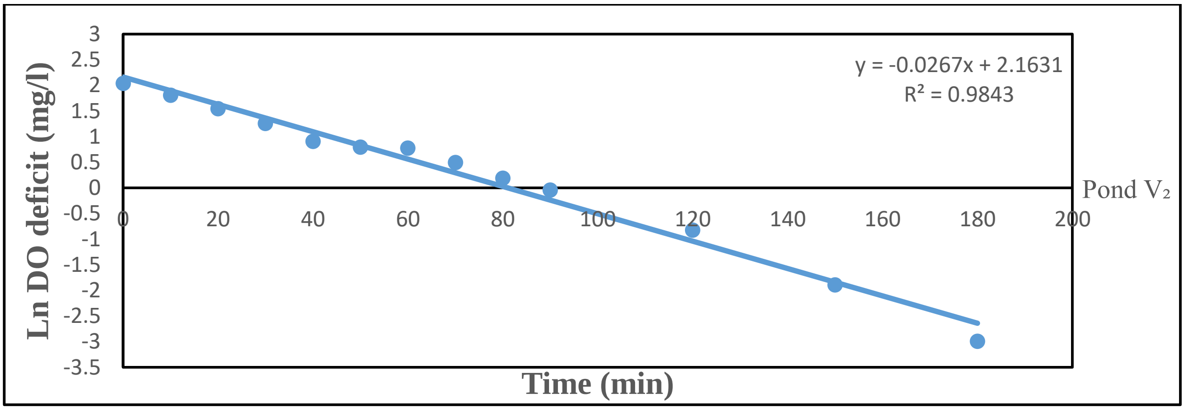

Fig. 11. Relationship between Ln DO deficit and time (Vertical perforated cylindrical aerator)

The DO deficit values of vertical perforated cylindrical aerator of the pond V_2 was plotted versus time shown in (Fig. 11). The slope of the graph gave the K_La value of the aerator at the water temperature of 28 °C.

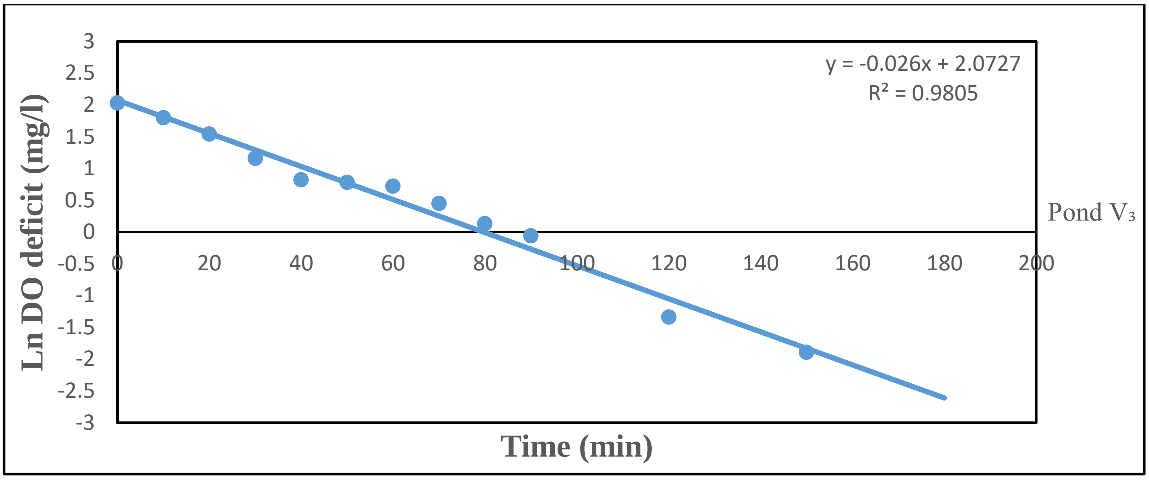

Fig. 12. Relationship between Ln DO deficit and time (Vertical perforated cylindrical aerator)

Using the vertical perforated cylindrical aerator measured pond water DO deficit values (in log scale) was plotted in Y- axis versus time in X- axis as straight line. At the pond water temperature of 28 °C the K_L a value of aerator was determined using the slope of the graph.

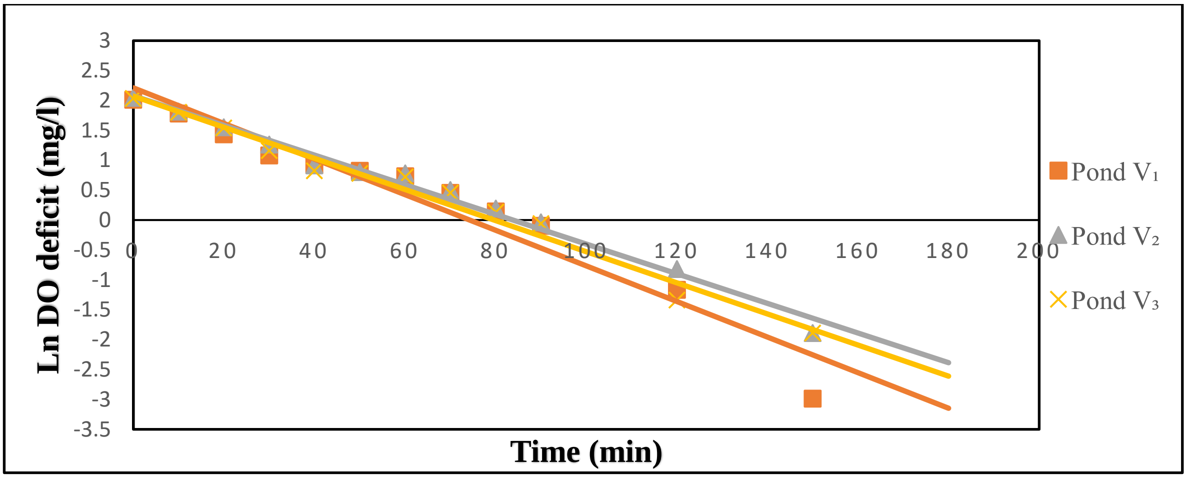

Fig. 13. Comparison of Ln DO deficit and time (Vertical perforated cylindrical aerators)

identified that the pond V_1 shows better ($K_L a_T$) and SOTR value compared to V_2 and V_3 ponds respectively.

4.7. Three tier perforated tray aerator (Pond T_1)

In the present study initial recorded water temperature at the ponds was 24 °C. The pond water was deoxygenated first and DO content measured was 0.48 mg/l. Using the three tier perforated tray aerator the pond water DO was increased and measured after three hours and it was 8.52 mg/l. Beginning of the experiment the DO level increased rapidly and then increased slowly until it reached the final value. Increase in DO concentration in pond water was given in the table 3 and plotted graphically in Fig.14.

The overall oxygen-transfer coefficient ($K_L a_T$) and Standard Oxygen Transfer Rate were recorded as 1.602 h^{-1} and 0.165 kg O_2/h respectively.

4.8. Three tier perforated tray aerator (Pond T_2)

The dissolved oxygen content in the pond water ranged between 0.35 mg/l to 8.32 mg/l. The minimum 0.35 mg/l was recorded in the beginning and maximum of 8.32 mg/l was noticed at the end of the experiment. Rise in DO concentration in pond water is given in the table 3 plotted graphically in Fig.15.

Whereas the overall oxygen-transfer coefficient ($K_L a_T$) raised upto1.518 h^{-1}. The Standard Oxygen Transfer Rate reached upto 0.156 kg O_2/h.

4.9. Three tier perforated tray aerator (Pond T_3)

The DO content of the pond water measured during the study period fluctuated from 0.40 mg/l to 8.40 mg/l. The greater value of DO was measured after three hours and minimum DO value was noticed in the beginning of the experiment. Increase in DO of the Pond T_3 water is similar to that of other two ponds. Increase in DO concentration in pond water was presented in the table 3 and shown graphically in Fig.16.

The investigational values of oxygen deficit versus time for all three ponds using three tier perforated tray aerators are portrayed graphically in Fig.17. From the graph it was noticed that the pond T_1 displays better ($K_L\ a_T$) and SOTR value followed by T_2 and T_3 ponds respectively.

4.10. Rotating wheel aerator (Pond R_1)

The initial temperature of pond water was recorded as 29 °C. The pond water was deoxygenated in the beginning and DO content measured was 0.12 mg/l. Using the above aerator the pond water DO was raised up for a duration of three hours and it was measured as 7.40 mg/l. Initially, the oxygen level increased rapidly and then gently increased until it reached final value. Rise in dissolved oxygen content in pond water was recorded in the table 4 and graphically depicted in Fig.18.

The overall oxygen-transfer coefficient ($K_L\ a_T$) and (SOTR) Standard Oxygen Transfer Rate were calculated as 1.170 h^{-1} and 0.107 kg O_2/h respectively.

Table 3. Increase of dissolved oxygen content in the ponds water using three tier perforated tray aerator

Time (Min)	Pond (T_1)					Pond (T_2)					Pond (T_3)				
	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)
	S_1	S_2	Avg.			S_1	S_2	Avg.			S_1	S_2	Avg.		
0	0.48	0.38	0.43	7.97	2.07	0.33	0.37	0.35	8.05	2.08	0.40	0.41	0.40	8.00	2.07
10	2.23	2.11	2.17	6.23	1.82	2.07	2.19	2.13	6.27	1.83	2.91	2.51	2.71	5.69	1.73
20	2.99	3.05	3.02	5.38	1.68	2.89	2.96	2.92	5.48	1.70	3.11	2.99	3.05	5.35	1.67
30	3.97	3.77	3.87	4.53	1.51	3.67	4.07	3.87	4.53	1.51	3.67	3.87	3.77	4.63	1.53
40	5.24	4.23	4.73	3.67	1.30	4.25	4.43	4.34	4.06	1.40	4.25	4.53	4.39	4.10	1.38
50	4.35	5.57	4.96	3.44	1.23	5.00	5.32	5.16	3.24	1.17	5.57	4.53	5.05	3.35	1.20
60	6.31	5.97	6.14	2.26	0.81	5.57	6.19	5.88	2.52	0.92	5.97	6.43	6.20	2.20	0.78
70	6.43	6.43	6.43	1.97	0.67	6.53	6.23	6.38	2.02	0.70	6.19	6.31	6.25	2.15	0.76
80	6.31	6.73	6.52	1.88	0.63	7.07	6.37	6.72	1.68	0.51	6.70	6.59	6.64	1.76	0.56
90	7.17	7.23	7.20	1.20	0.18	7.00	6.80	6.90	1.50	0.40	6.99	7.50	7.24	1.16	0.14
120	7.98	8.00	7.99	0.41	-0.89	7.98	7.40	7.69	0.71	-0.34	7.40	8.00	7.70	0.70	-0.35
150	8.18	8.40	8.29	0.11	-2.20	8.40	8.08	8.24	0.16	-1.83	8.40	8.03	8.21	0.19	-1.66
180	8.50	8.55	8.52	-	-	8.40	8.25	8.32	0.08	-2.52	8.50	8.31	8.40	-	-

Source: Colt (1984) **Cs = 8.40** for a temperature of 24 °C and standard atmospheric pressure.

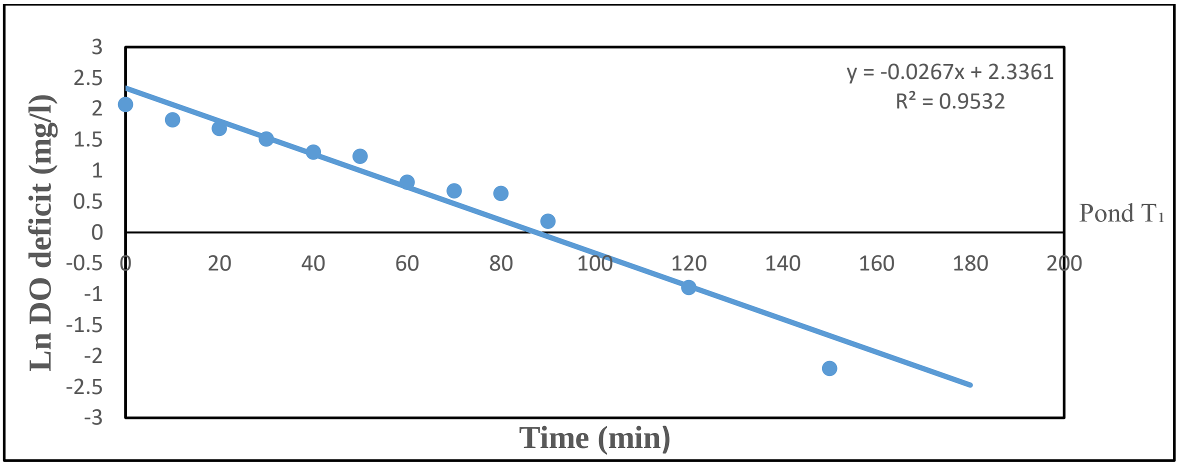

Fig. 14. Relationship between Ln DO deficit and time (Three tier perforated tray aerator)

The DO deficit values (in log scale) of three tier perforated tray aerator was plotted versus time as straight line (Fig. 14). The slope of the above graph used to calculate the K_La value of the aerator at the water temperature of 24 °C.

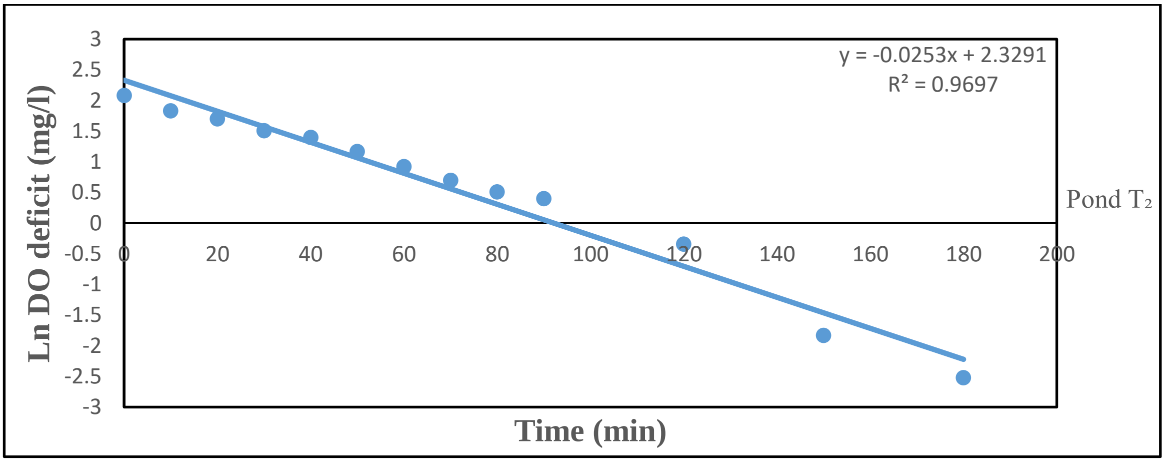

Fig. 15. Relationship between Ln DO deficit and time (Three tier perforated tray aerator)

The DO deficit values of three tier perforated tray aerator was plotted against time and shown in (Fig. 15). The slope of the line gave the K_La value of the aerator at the water temperature of 24 °C.

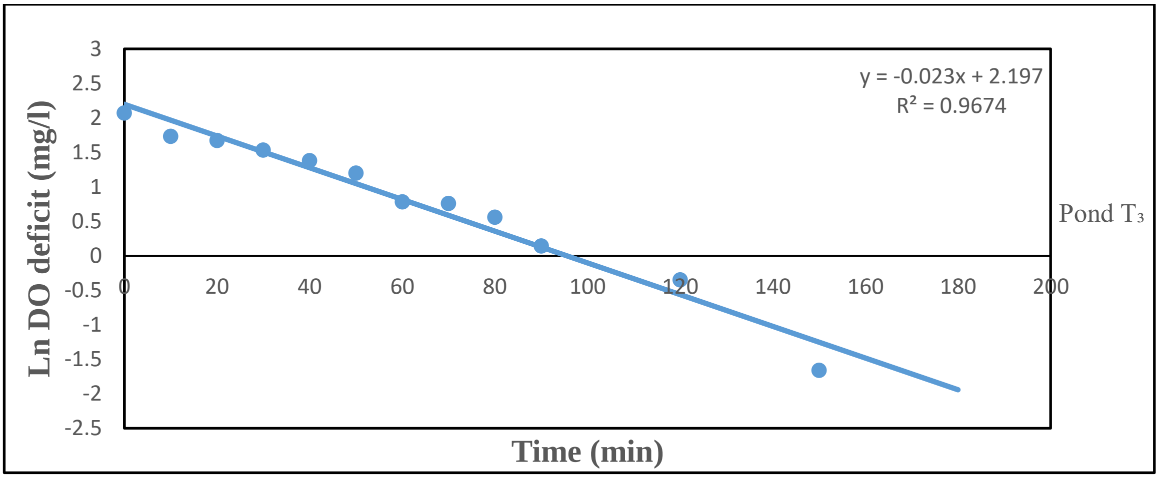

Fig. 16. Relationship between Ln DO deficit and time (Three tier perforated tray aerator)

The graph (Fig. 16) shown the DO deficit values (in log scale) of the three tier perforated tray aerator was plotted against the time (straight line) taken for conducting the experiment. The K_La value of the aerator for a temperature of 24 °C was calculated using the slope of the graph.

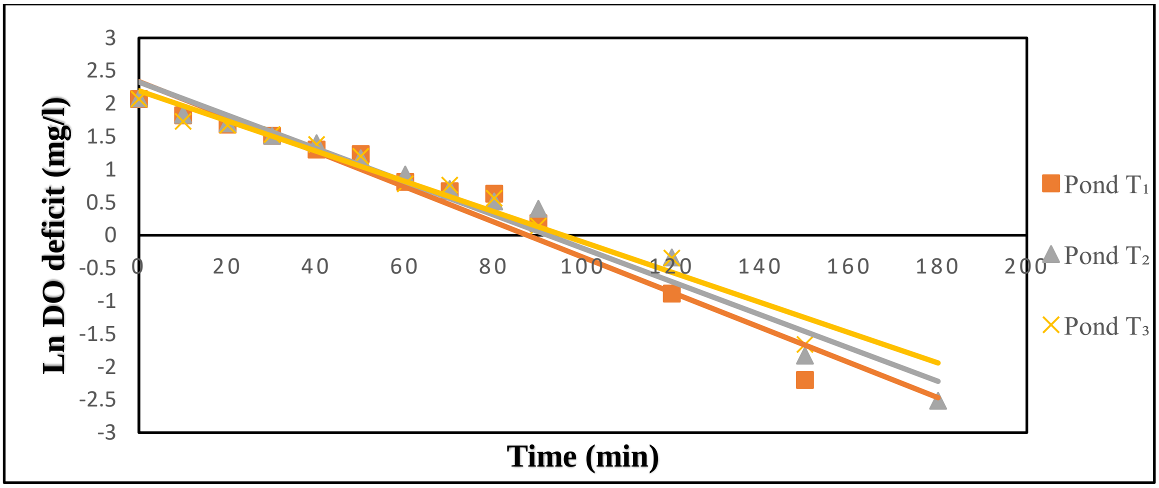

Fig. 17. Comparison of Ln DO deficit and time (Three tier perforated tray aerators)

4.11. Rotating wheel aerator (Pond R_2)

In the current study initial recorded pond water temperature was 29 °C. The pond water was deoxygenated first and DO content measured was 0.25 mg/l. The rotating wheel aerator was turned on and the pond water DO was increased for a duration of three hours and it was shown 7.36 mg/l at the end of the experiment. At the beginning, the DO level increased rapidly and then increased slowly until it reached the final value. Increase in DO concentration in pond water was given in the table 4 and plotted graphically in Fig.19.

The Standard Oxygen Transfer Rate (SOTR) and the overall oxygen-transfer coefficient ($K_L\, a_T$) values of the above aerator were found 0.102 kg O_2/h and 1.122 h^{-1} respectively.

4.12. Rotating wheel aerator (Pond R_3)

The pond (R_3) water temperature was measured initially and it was also 29 °C. The pond water was deoxygenated for a period of 30 minutes and measured DO value was 0.40 mg/l. After re-oxygenated the pond water, the DO was measured and it was 7.32 mg/l. Initially DO concentration of pond water increased rapidly and increased slowly up to the end point of experiment. Increase in DO concentration in pond water was reported in the table 4 and presented graphically in Fig.20.

The overall oxygen-transfer coefficient ($K_L\, a_T$) reached upto 1.086 h^{-1} and (SOTR) Standard Oxygen Transfer Rate raised upto 0.099 kg O_2/h respectively.

The experimental values of deficit of oxygen versus time for all three ponds using rotating wheel aerators are portrayed graphically in Fig.21. From the graph it was observed that the pond R_1 shows better ($K_L\, a_T$) and SOTR value compared to R_2 and R_3 ponds.

Table 4. Increase of dissolved oxygen content in the ponds water using rotating wheel aerator

Time (Min)	Pond (R_1)					Pond (R_2)					Pond (R_3)				
	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)
	S_1	S_2	Avg.			S_1	S_2	Avg.			S_1	S_2	Avg.		
0	0.10	0.15	0.12	7.55	2.02	0.30	0.20	0.25	7.42	2.00	0.36	0.45	0.40	7.27	1.98
10	1.22	1.25	1.23	6.44	1.86	1.19	1.29	1.24	6.43	1.86	1.20	1.30	1.25	6.42	1.85
20	2.49	2.45	2.47	5.2	1.64	2.45	2.31	2.38	5.29	1.66	2.39	2.48	2.43	5.24	1.65
30	4.50	4.46	4.48	3.19	1.16	4.49	4.55	4.52	3.15	1.14	4.35	4.55	4.45	3.22	1.16
40	4.48	4.48	4.48	3.19	1.16	4.40	4.50	4.45	3.22	1.16	4.41	4.52	4.46	3.21	1.16
50	4.81	4.88	4.84	2.83	1.04	4.80	4.89	4.84	2.83	1.04	5.00	4.91	4.95	2.72	1.00
60	5.30	5.26	5.28	2.39	0.87	5.10	5.56	5.33	2.34	0.85	5.30	5.46	5.38	2.29	0.82
70	5.79	5.71	5.75	1.92	0.65	5.69	5.91	5.80	1.87	0.62	5.59	5.81	5.70	1.97	0.67
80	6.01	6.15	6.08	1.59	0.46	6.21	6.15	6.18	1.49	0.39	6.31	6.25	6.28	1.39	0.32
90	6.50	6.52	6.51	1.16	0.14	6.30	6.72	6.51	1.16	0.14	6.30	6.82	6.56	1.11	0.10
120	6.90	6.98	6.94	0.73	-0.31	7.10	6.98	7.04	0.63	-0.46	7.12	7.11	7.11	0.56	-0.57
150	7.34	7.44	7.39	0.28	-1.27	7.29	7.33	7.31	0.36	-1.02	7.21	7.30	7.25	0.42	-0.86
180	7.44	7.36	7.40	0.27	-1.3	7.39	7.34	7.36	0.31	-1.17	7.29	7.35	7.32	0.35	-1.04

Source: Colt (1984) **Cs = 7.67** for a temperature of 29 °C and standard atmospheric pressure.

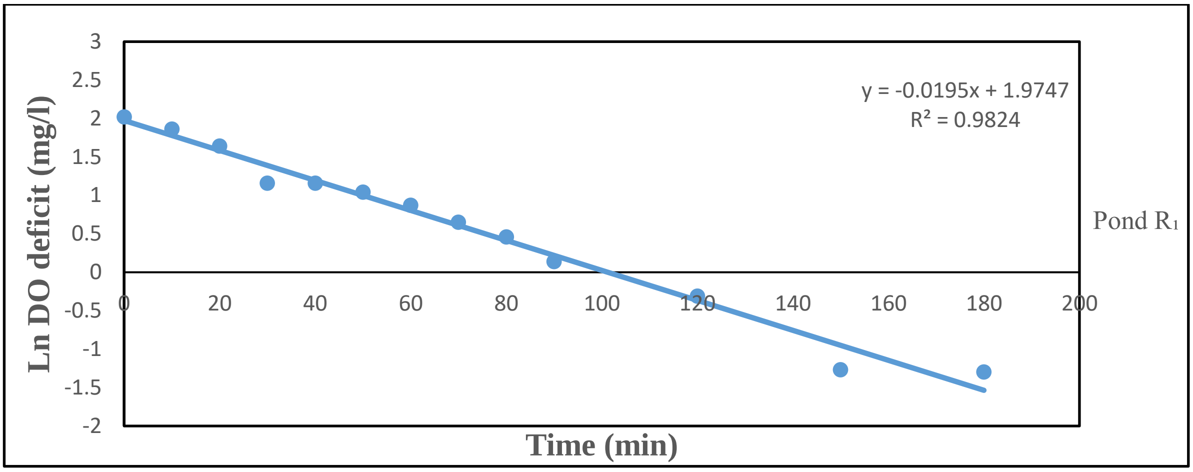

Fig. 18. Relationship between Ln DO deficit and time (Rotating wheel aerator)

The DO deficit values (in log scale) of rotating wheel aerator was plotted versus time as straight line (Fig. 18). The slope of the line gave the K_La value of the aerator at the water temperature of 29 °C.

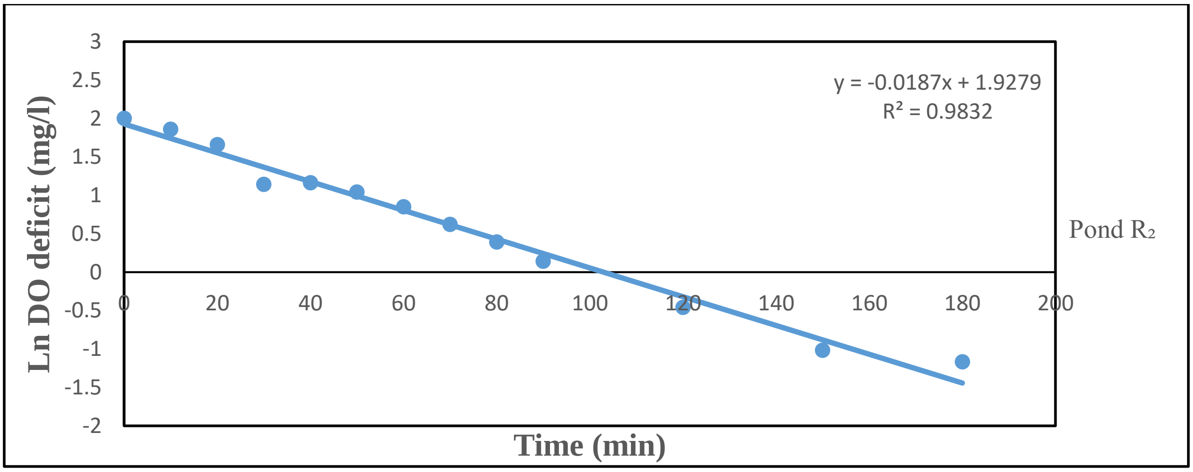

Fig. 19. Relationship between Ln DO deficit and time (Rotating wheel aerator)

Changes in the DO deficit values (in log scale) of rotating wheel aerator was plotted versus time as straight line in the (Fig. 19). The slope obtained was negative. The K_La value of the aerator at the water temperature of 29 °C was calculated using the slope of the graph.

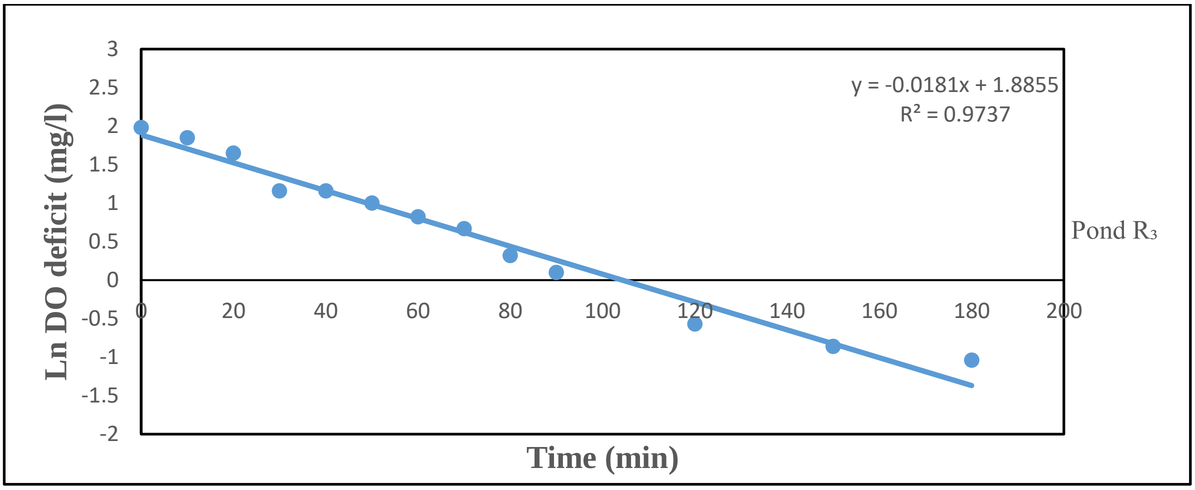

Fig. 20. Relationship between Ln DO deficit and time (Rotating wheel aerator)

The DO deficit values of pond R_3 water using rotating wheel aerator was plotted versus time represented in (Fig. 20). The K_La value of the aerator at the water temperature of 29 °C was calculated using the above slope.

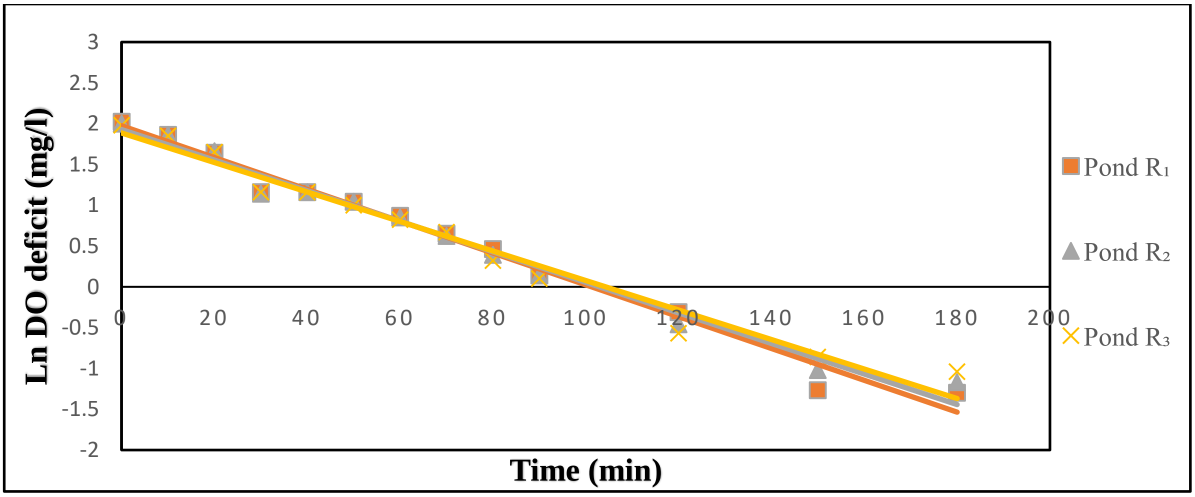

Fig. 21. Comparison of Ln DO deficit and time (Rotating wheel aerators)

4.13. Cascading wooden plank aerator (Pond C_1)

The pond water was initially deoxygenated and DO content measured was 0.03 mg/l. Using the cascading wooden plank aerator the pond water DO was increased and measured after three hours and it was 7.42 mg/l. Beginning of the experiment the DO level increased sharply and then increased slowly until it reached the final value. Increase in DO concentration in pond water was presented in the table 5 and graphically depicted in Fig.22.

The overall oxygen-transfer coefficient ($K_L a_T$) and (SOTR) Standard Oxygen Transfer Rate were 1.062 h^{-1} and 0.097 kg O_2/h respectively.

4.14. Cascading wooden plank aerator (Pond C_2)

The pond water was deoxygenated first and DO content measured was 0.24 mg/l. The cascading wooden plank aerator was turned on and the pond water DO was increased for a duration of three hours and it was shown 7.21 mg/l. At the beginning, the DO level increased rapidly and then increased slowly until it reached the final value. Increase in DO concentration in pond water was presented in the table 5 and Fig.23.

The overall oxygen-transfer coefficient ($K_L a_T$) reached upto 0.924 h^{-1} and (SOTR) Standard Oxygen Transfer Rate reached upto 0.084 kg O_2/h respectively.

4.15. Cascading wooden plank aerator (Pond C_3)

The DO content of pond C_3 water was measured during the study period it ranged from 0.20 mg/l to 7.14 mg/l. The higher value of DO measured after three hours of duration and least DO was noticed in the beginning of the experiment. After the aerator turned on the DO

Table 5. Increase of dissolved oxygen content in the ponds water using cascading wooden plank aerator

Time (Min)	Pond (C_1)					Pond (C_2)					Pond (C_3)				
	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)	DO measured (mg/l) (Cm)			DO deficit (mg/l) (Cs-Cm)	ln DO deficit (mg/l)
	S_1	S_2	Avg.			S_1	S_2	Avg.			S_1	S_2	Avg.		
0	0	0.03	0.03	7.64	2.03	0.22	0.26	0.24	7.43	2.00	0.23	0.18	0.20	7.47	2.01
10	0.53	0.49	0.51	7.61	1.96	0.74	0.87	0.80	6.87	1.92	0.72	0.81	0.76	6.92	1.93
20	1.55	1.37	1.46	6.21	1.82	2.04	1.78	1.91	5.76	1.72	2.03	1.58	1.80	5.87	1.76
30	2.45	2.37	2.41	5.26	1.66	2.85	2.93	2.89	4.78	1.56	1.94	1.83	1.88	5.79	1.75
40	2.24	3.06	2.65	5.02	1.61	3.18	3.03	3.10	4.57	1.51	2.46	2.57	2.51	5.16	1.64
50	3.66	3.79	3.72	3.95	1.37	3.93	4.01	3.97	3.70	1.30	3.25	3.77	3.51	4.16	1.42
60	4.07	4.21	4.14	3.53	1.26	4.21	4.40	4.30	3.37	1.21	4.49	4.27	4.38	3.29	1.19
70	4.60	4.22	4.41	3.26	1.81	4.53	4.60	4.56	3.11	1.13	4.48	4.36	4.42	3.25	1.17
80	4.90	4.63	4.76	2.91	1.06	4.83	4.91	4.87	2.80	1.02	4.76	4.57	4.66	3.01	.10
90	5.69	5.98	5.83	1.84	0.60	5.73	5.83	5.78	1.89	0.63	5.21	5.54	5.37	2.30	0.83
120	6.62	6.58	6.6	1.07	0.06	6.65	6.52	6.58	1.09	0.08	6.06	6.52	6.29	1.38	0.32
150	6.89	6.63	6.76	0.91	-0.09	6.80	6.80	6.80	0.87	-0.13	6.50	6.25	6.37	1.30	0.26
180	7.42	7.42	7.42	0.25	-1.38	6.98	7.45	7.21	0.46	-0.77	7.21	7.08	7.14	0.53	-0.63

Source: Colt (1984) **Cs = 7.67** for a temperature of 29 °C and standard atmospheric pressure.

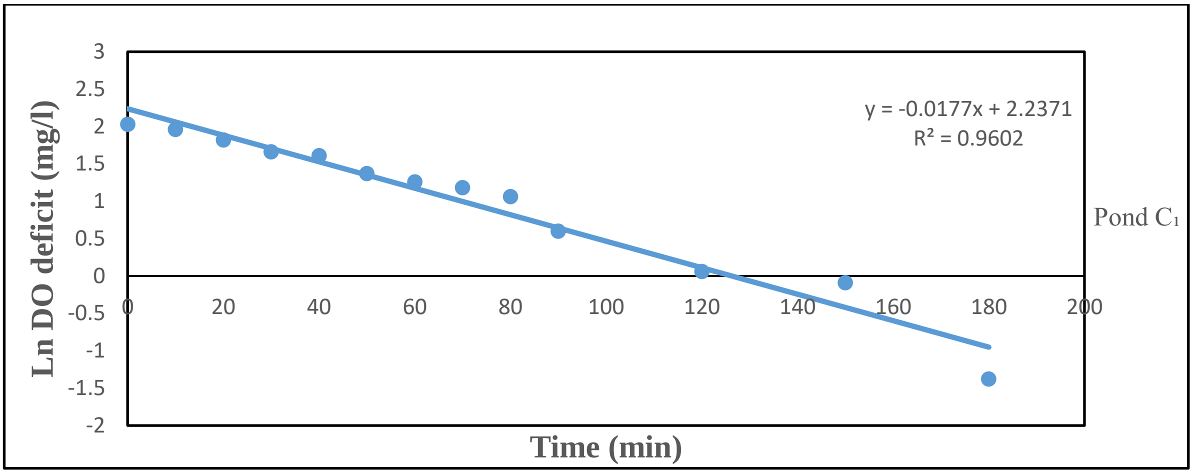

Fig. 22. Relationship between Ln DO deficit and time (Cascading wooden plank aerator)

The DO deficit values of pond C_1 water using cascading wooden plank aerator was plotted versus time of aeration is represented in (Fig. 22). The K_La value of the aerator at the water temperature of 29 °C was calculated using the above slope.

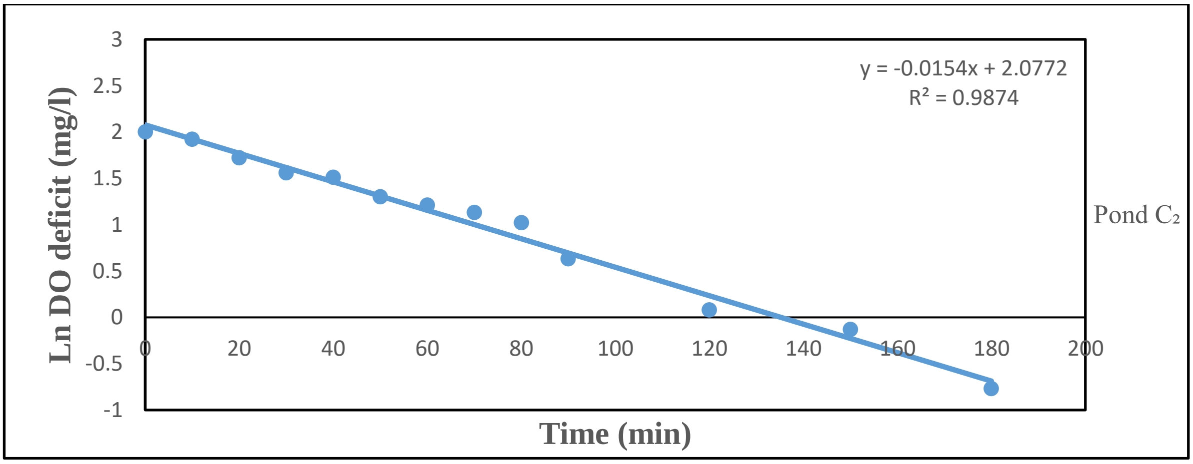

Fig. 23. Relationship between Ln DO deficit and time (Cascading wooden plank aerator)

The DO deficit values (in log scale) of cascading wooden plank aerator was plotted against time as straight line (Fig. 23). The slope of the line gave the K_La value of the aerator at the water temperature of 29 °C.

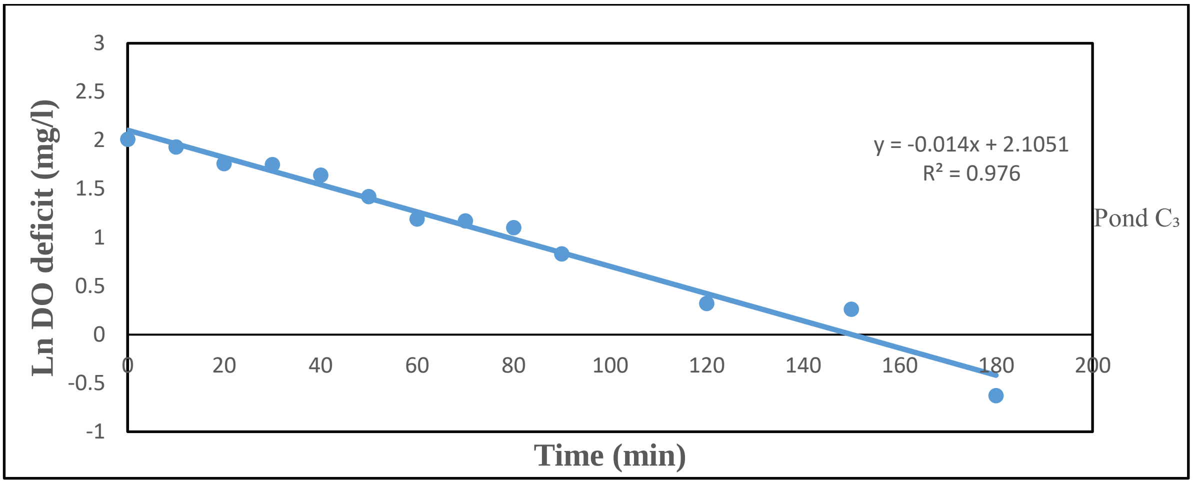

Fig. 24. Relationship between Ln DO deficit and time (Cascading wooden plank aerator)

The DO deficit values (in log scale) of cascading wooden plank aerator was plotted against time as straight line (Fig. 24). Using the above shape of the graph was calculated. The slope of the line gave the K_La value of the aerator at the water temperature of 29 °C.

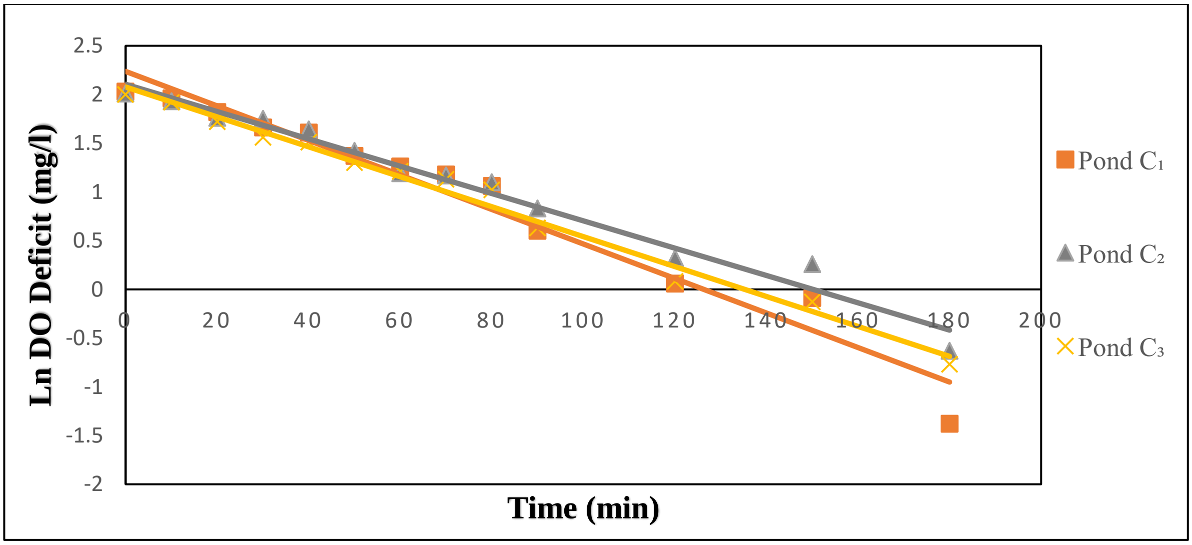

Fig. 25. Comparison of Ln DO deficit and time (Cascading wooden plank aerators)

concentration rises rapidly, later on increased slowly. Increase in DO concentration of pond water was given in the table 5 and shown graphically in Fig.24.

The overall oxygen-transfer coefficient ($K_L a_T$) reached upto 0.840 h $^{-1}$ and (SOTR) Standard Oxygen Transfer Rate raised upto 0.077 kg O_2/h respectively.

The observed values of deficit of oxygen versus time for all three ponds using cascading wooden plank aerators are plotted graphically in Fig.25. From the graph it was detected that the pond C_1 shows better ($K_L a_T$) and SOTR value followed by C_2 and C_3 ponds respectively.

4.16. Comparison of the better aerated ponds

In the beginning of the study, water temperature recorded as 27 °C, 29 °C, 29 °C, 24 °C and 28 °C in W_1, C_1, R_1, T_1 and V_1 ponds respectively. The DO content initially measured were 0.43 mg/l, 0.03 mg/l, 0.12 mg/l, 0.48 mg/l and 0.33 mg/l in the above ponds respectively. The dissolved oxygen content increased in all the ponds and finally it reached the values of 4.20 mg/l, 7.42 mg/l, 7.40 mg/l, 8.52 mg/l and 8.07 mg/l in the above mentioned ponds.

The observed values of DO deficit versus time for all ponds are depicted graphically in Fig.26. From the graph it was observed that the vertical perforated cylindrical aerator shows better ($K_L a_T$) and SOTR value followed by three tier perforated tray aerator, rotating wheel aerator and cascading wooden plank aerator respectively.

4.17. Comparison of increased dissolved oxygen content in the ponds water

Initially the water temperature measured as 27 °C, 29 °C, 29 °C, 24 °C and 28 °C in W_1, C_1, R_1, T_1 and V_1 ponds respectively. The initial DO content recorded during the study period were 0.43 mg/l, 0.03 mg/l, 0.12 mg/l, 0.48 mg/l and 0.33 mg/l in ponds W_1, C_1, R_1, T_1 and V_1

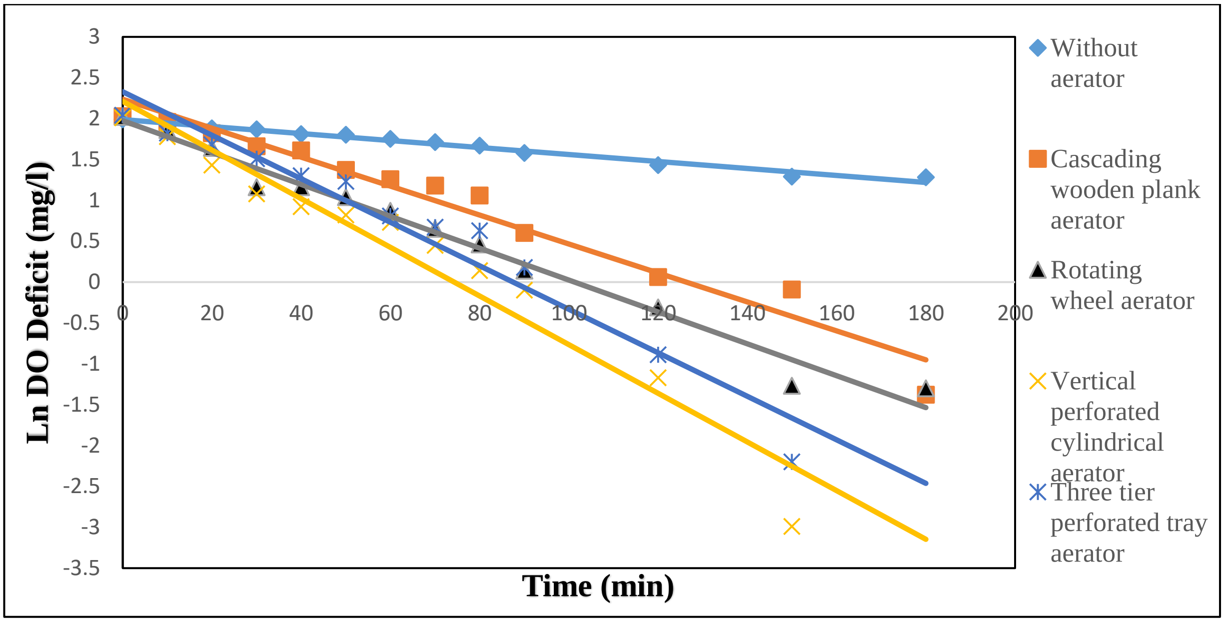

Fig. 26. Comparison of Ln DO deficit verses time (All the better ponds)

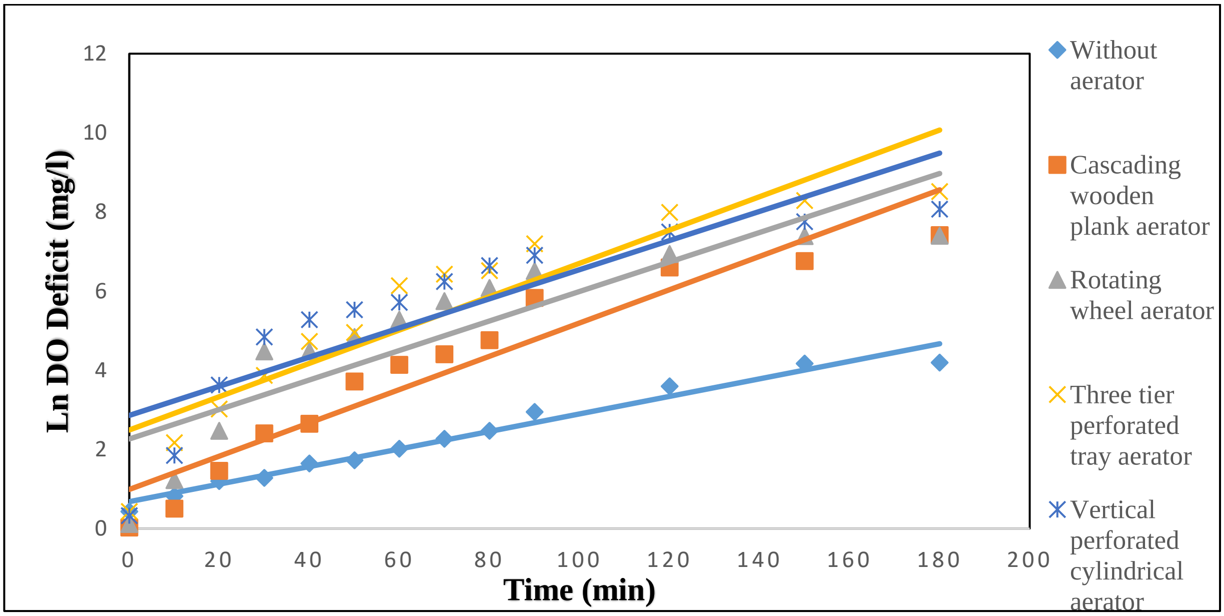

Fig. 27. Comparison of increased DO (mg/l) and time (All the better ponds)

respectively. The dissolved oxygen content increased in all ponds and finally it reached the values of 4.20 mg/l, 7.42 mg/l, 7.40 mg/l, 8.52 mg/l and 8.07 mg/l in the above mentioned ponds. Increased in dissolved oxygen content of the above ponds water represented graphically in the Fig.27.

4.18. Dissolution of oxygen in the pond water

Plants growing in water produce oxygen by photosynthesis and during daylight hours plants in aquaculture ponds often produce oxygen so fast that DO concentration in water rises above saturation. Water also may contain less DO than expected at saturation. At night, respiration by fish, plants and other pond organisms causes DO concentrations to decline. With this back ground experiment has been carried out to study the dissolution of oxygen in the pond water during day and night time.

4.18.1. Dissolution of oxygen without using aerator during day time

Experiments were carried out in triplicate as W_1, W_2 and W_3 during day time without using aerator. The water temperature of 28 °C was measured initially in all three ponds. At the beginning of the experiment dissolved oxygen content of water were 6.95 mg/l, 6.19 mg/l, and 7.15 mg/l in ponds W_1, W_2 and W_3 respectively. The dissolved oxygen content of the pond water increased slowly during the experiment and finally it reached the values of 7.63 mg/l, 7.26 mg/l and 7.76 mg/l in the above ponds respectively. Increase in dissolved oxygen content of the pond water is shown in table 6 and portrayed graphically in the Fig.28.

Table 6. Increase of dissolved oxygen content in the ponds water during day time (Without using aerators)

Time (Min)	Pond W_1			Pond W_2			Pond W_3		
	DO measured (mg/l)			DO measured (mg/l)			DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	6.75	7.16	6.95	6.27	6.12	6.19	7.08	7.23	7.15
30	7.01	7.20	7.10	6.67	6.59	6.63	7.23	7.30	7.26
60	7.21	7.01	7.11	6.86	6.35	6.60	7.30	7.23	7.26
90	7.33	7.21	7.27	6.77	6.80	6.78	7.25	7.30	7.27
120	7.35	7.40	7.37	7.08	6.92	7.00	7.57	7.28	7.42
150	7.43	7.42	7.42	6.99	7.22	7.10	7.62	7.44	7.53
180	7.62	7.54	7.58	7.22	7.31	7.26	7.72	7.65	7.68
210	7.54	7.72	7.63	7.22	7.31	7.26	7.86	7.65	7.75

Table 7. Decrease of dissolved oxygen content in the ponds water during night time (Without using aerators)

Time (Min)	Pond W_1			Pond W_2			Pond W_3		
	DO measured (mg/l)			DO measured (mg/l)			DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	8.32	8.54	8.43	8.50	8.66	8.58	8.87	8.59	8.73
30	8.13	8.03	8.08	8.00	8.04	8.02	8.37	8.45	8.41
60	7.85	7.82	7.83	7.82	7.82	7.82	8.31	8.43	8.37
90	7.77	7.69	7.73	7.63	7.69	7.66	7.90	7.83	7.86
120	7.69	7.51	7.60	7.44	7.48	7.46	7.67	7.74	7.70
150	7.37	7.31	7.34	7.18	7.22	7.20	7.62	7.58	7.60
180	7.15	7.18	7.16	7.01	7.10	7.05	7.22	7.39	7.30
210	7.03	7.14	7.08	7.00	6.99	6.99	7.18	7.16	7.17

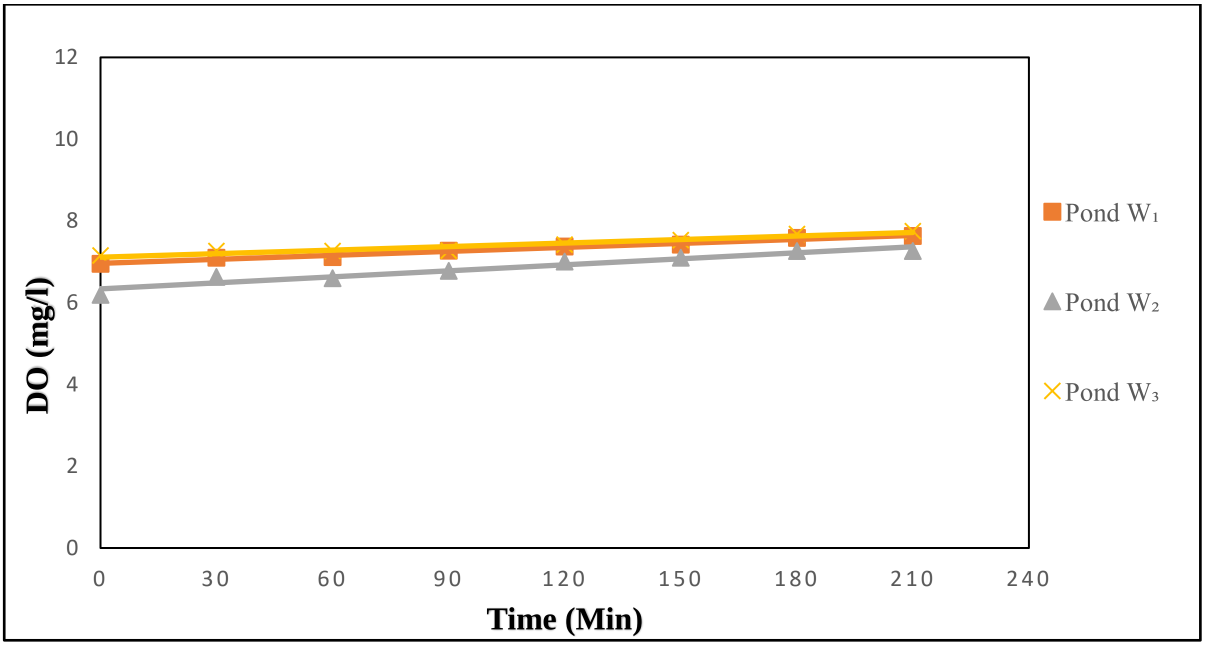

Fig. 28. Increase of dissolved oxygen content during day time (Without using aerators)

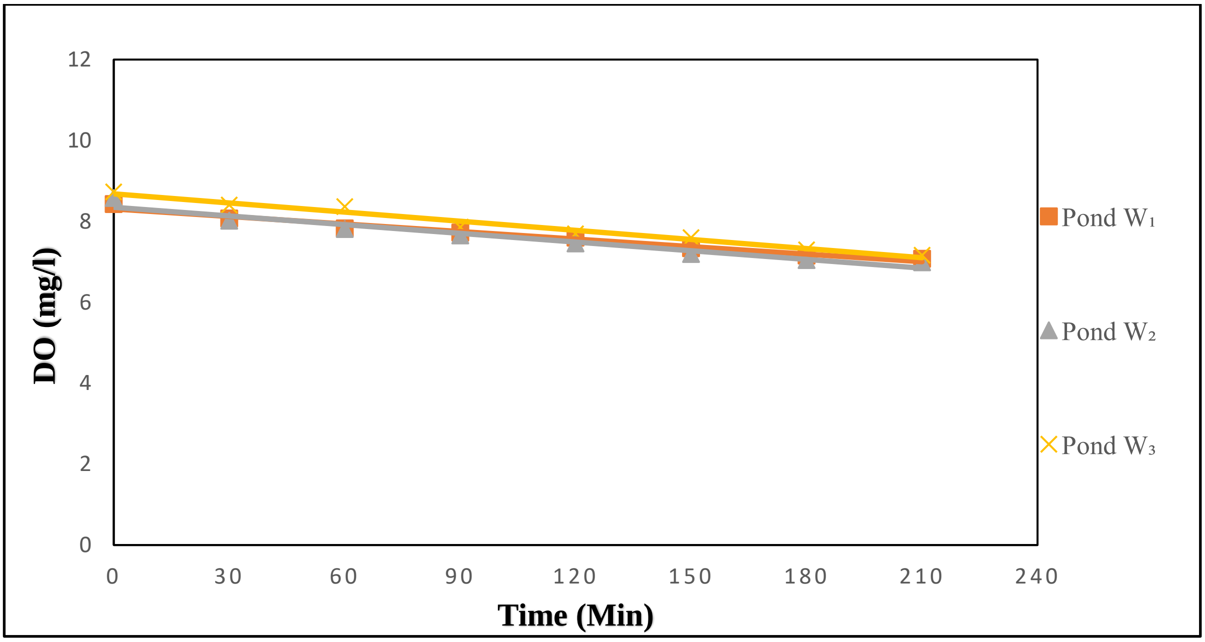

Fig. 29. Decrease of dissolved oxygen content during night time (Without using aerators)

4.18.2. Dissolution of oxygen without using aerator during night time

Without using the aerator experiments have been carried out during night time to find out the dissolution of oxygen in pond water. Initially the pond water temperature was recorded as 31 °C in all three ponds. The dissolved oxygen content in the ponds water were measured in the beginning of the experiment and it was 8.43 mg/l, 8.58 mg/l and 8.73 mg/l in ponds W_1, W_2 and W_3 respectively. The pond water dissolved oxygen content gradually decreased until it reaches the final values of 7.08 mg/l, 6.99 mg/l and 7.17 mg/l in W_1, W_2 and W_3 ponds respectively. The decrease in dissolved oxygen content of the pond water presented in the table 7 and shown graphically in the Fig.29.

4.18.3. Dissolution of oxygen using rotating wheel aerators during day time

Experiments have been carried out using the rotating wheel aerator in three ponds such as R_1, R_2 and R_3 during day time. The water temperature of 28 °C was recorded in all three ponds in the beginning of the experiment. The DO content initially recorded during the study period were 6.71 mg/l, 6.66 mg/l and 6.43 mg/l in ponds R_1, R_2 and R_3 respectively. Rotating wheel aerators were used to increase the DO content of the pond water, initially DO concentration of pond water increased rapidly, increased slowly for some period and finally it reached the values of 8.02 mg/l, 7.79 mg/l and 7.87 mg/l in the above ponds respectively. Increase in dissolved oxygen content of the pond water shown in table 8 and represented graphically in the Fig.30.

Table 8. Increase of dissolved oxygen content in the ponds water during day time (Rotating wheel aerators)

Time (Min)	Pond R_1 DO measured (mg/l)			Pond R_2 DO measured (mg/l)			Pond R_3 DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	6.42	7.00	6.71	6.22	7.10	6.66	6.10	6.77	6.43
30	6.88	7.23	7.05	6.74	7.00	6.87	6.98	7.26	7.12
60	7.65	7.57	7.61	7.20	7.40	7.30	7.45	7.04	7.24
90	7.59	7.67	7.63	7.31	7.41	7.36	7.49	7.28	7.38
120	7.59	7.64	7.61	7.33	7.45	7.39	7.38	7.55	7.46
150	7.63	7.76	7.69	7.69	7.52	7.60	7.71	7.63	7.67
180	7.81	7.71	7.76	7.66	7.65	7.65	7.76	7.66	7.71
210	7.95	8.10	8.02	7.83	7.76	7.79	7.83	7.92	7.87

Table 9. Decrease of dissolved oxygen content in the ponds water during night time (Rotating wheel aerators)

Time (Min)	Pond R_1 DO measured (mg/l)			Pond R_2 DO measured (mg/l)			Pond R_3 DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	9.53	9.84	9.68	10.20	10.13	10.16	10.50	10.14	10.32
30	9.27	9.31	9.29	9.70	9.61	9.65	9.99	9.77	9.88
60	8.37	8.44	8.40	8.75	8.70	8.72	8.83	8.82	8.82
90	8.05	7.99	8.02	8.12	8.17	8.14	8.25	8.35	8.30
120	7.63	7.60	7.61	7.91	7.92	7.91	8.09	8.12	8.10
150	7.63	7.51	7.57	7.54	7.62	7.58	7.64	7.69	7.66
180	7.43	7.32	7.37	7.45	7.46	7.45	7.51	7.52	7.51
210	7.37	7.36	7.36	7.39	7.36	7.37	7.41	7.43	7.42

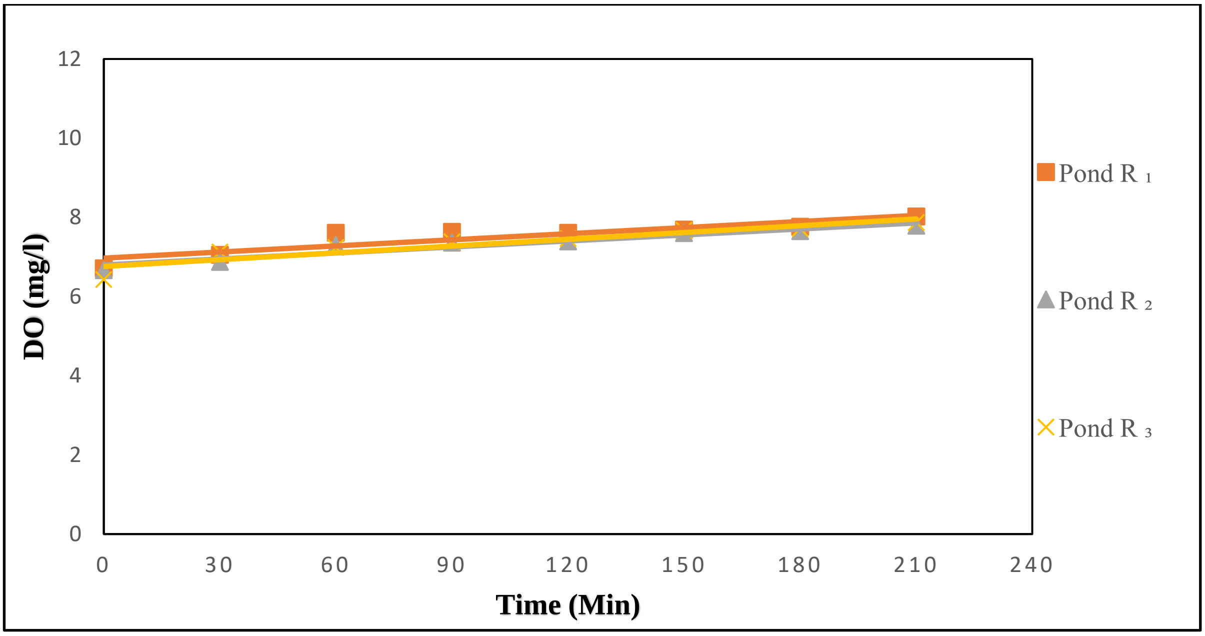

Fig. 30. Increase of dissolved oxygen content during day time (Rotating wheel aerators)

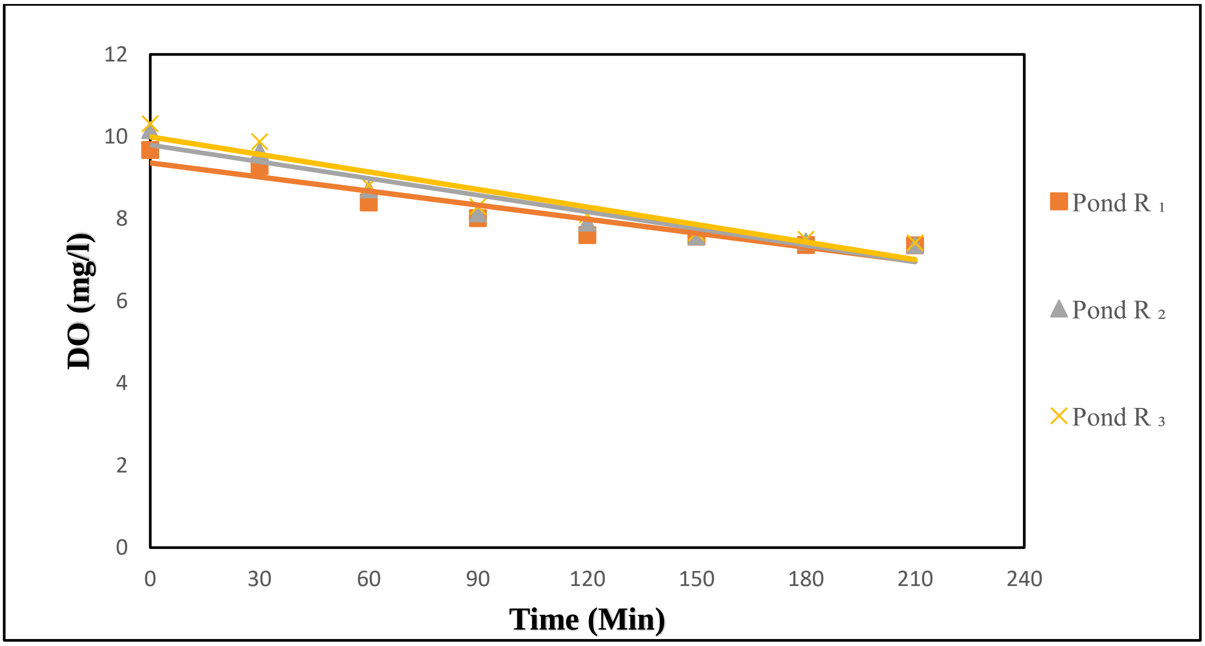

Fig. 31. Decrease of dissolved oxygen content during night time (Rotating wheel aerators)

4.18.4. Dissolution of oxygen using rotating wheel aerators during night time

Rotating wheel aerators were used to find out the dissolution of oxygen in pond water during night time. The same pond water temperature of 31 °C was noticed in all three ponds in the beginning. The dissolved oxygen content observed in the pond water were 9.68 mg/l, 10.16 mg/l and 10.32 mg/l in ponds R_1, R_2 and R_3 respectively in the beginning of the experiment. The dissolved oxygen content decreased gently during the study period and finally it reached the values of 7.36 mg/l, 7.37 mg/l and 7.42 mg/l in the ponds R_1, R_2 and R_3 correspondingly. Reduction in dissolved oxygen content of the pond water is presented in the table 9 and depicted graphically in the Fig.31.

4.18.5. Dissolution of oxygen using three tier perforated tray aerators during day time

Experiments have been carried out during day time to find out the dissolution of oxygen in pond water using three tier perforated tray aerators. The initial temperature of water recorded was 29 °C in all the three ponds. The dissolved oxygen content in the ponds water were observed initially as 7.05 mg/l, 6.90 mg/l and 6.79 mg/l in ponds T_1, T_2 and T_3 separately. The dissolved oxygen content increased gradually during the experiment period and finally it reached the values of 8.43 mg/l, 8.48 mg/l and 8.45 mg/l in the above mentioned ponds respectively. Increase in dissolved oxygen content of the pond water shown in the table 10 and portrayed graphically in the Fig.32.

4.18.6. Dissolution of oxygen using three tier perforated tray aerators during night time

To find out the dissolution of oxygen in ponds water using three tier perforated tray aerators experiments have been conducted during night time. In the beginning of the experiment

Table 10. Increase of dissolved oxygen content in the ponds water during day time (Three tier perforated tray aerators)

Time (Min)	Pond T_1 DO measured (mg/l)			Pond T_2 DO measured (mg/l)			Pond T_3 DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	6.80	7.30	7.05	6.67	7.13	6.90	6.85	6.73	6.79
30	7.90	8.01	7.95	7.80	7.96	7.88	7.76	7.53	7.64
60	8.03	7.97	8.00	7.91	7.94	7.92	7.84	7.61	7.72
90	8.15	8.08	8.11	7.90	7.95	7.92	7.77	7.88	7.82
120	8.12	8.18	8.15	8.03	7.98	8.00	8.05	7.98	8.01
150	8.24	8.13	8.18	8.10	7.99	8.04	8.16	8.03	8.09
180	8.41	8.21	8.31	8.13	8.20	8.16	8.30	8.11	8.20
210	8.30	8.57	8.43	8.41	8.55	8.48	8.37	8.53	8.45

Table 11. Decrease of dissolved oxygen content in the ponds water during night time (Three tier perforated tray aerators)

Time (Min)	Pond T_1 DO measured (mg/l)			Pond T_2 DO measured (mg/l)			Pond T_3 DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	8.45	8.59	8.52	8.41	8.61	8.51	9.72	9.65	9.68
30	7.61	7.45	7.53	7.03	7.17	7.10	8.87	8.67	8.77
60	7.18	7.15	7.16	6.91	6.89	6.90	8.45	8.37	8.41
90	7.01	6.99	7.00	6.86	6.76	6.81	7.61	7.53	7.57
120	6.80	6.79	6.79	6.66	6.57	6.61	7.41	7.39	7.40
150	6.76	6.51	6.63	6.50	6.49	6.49	7.18	7.21	7.19
180	6.68	6.49	6.58	6.34	6.41	6.37	6.86	6.88	6.87
210	6.58	6.37	6.47	6.23	6.33	6.28	6.76	6.71	6.73

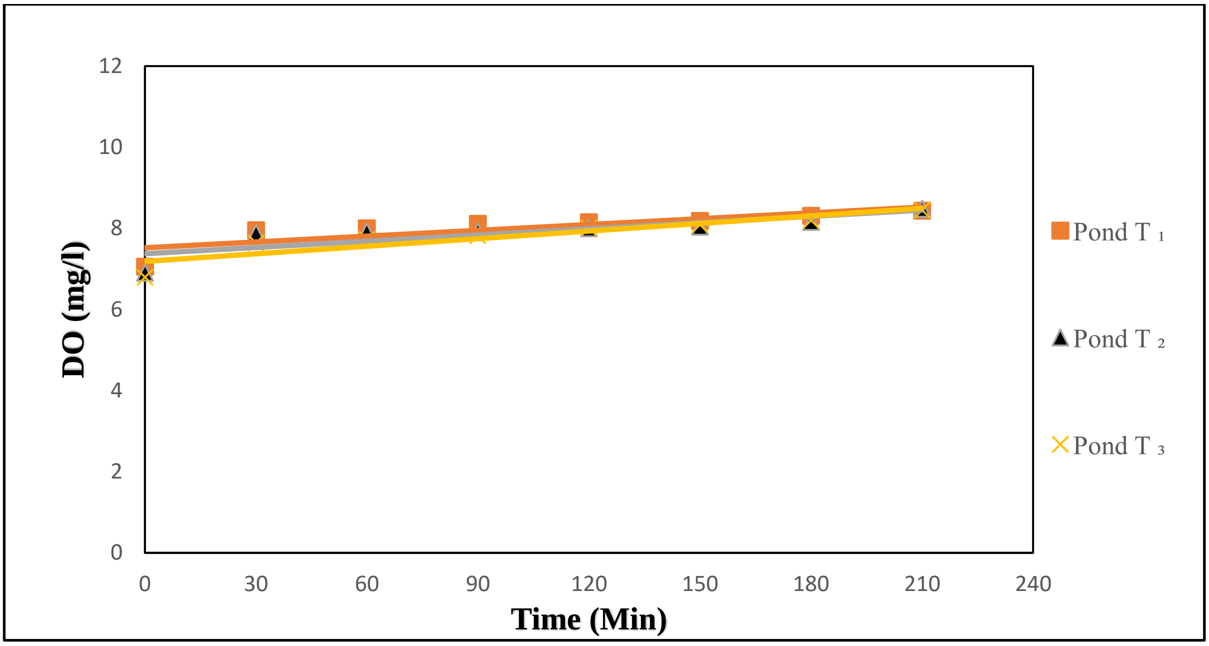

Fig. 32. Increase of dissolved oxygen content during day time (Three tier perforated tray aerators)

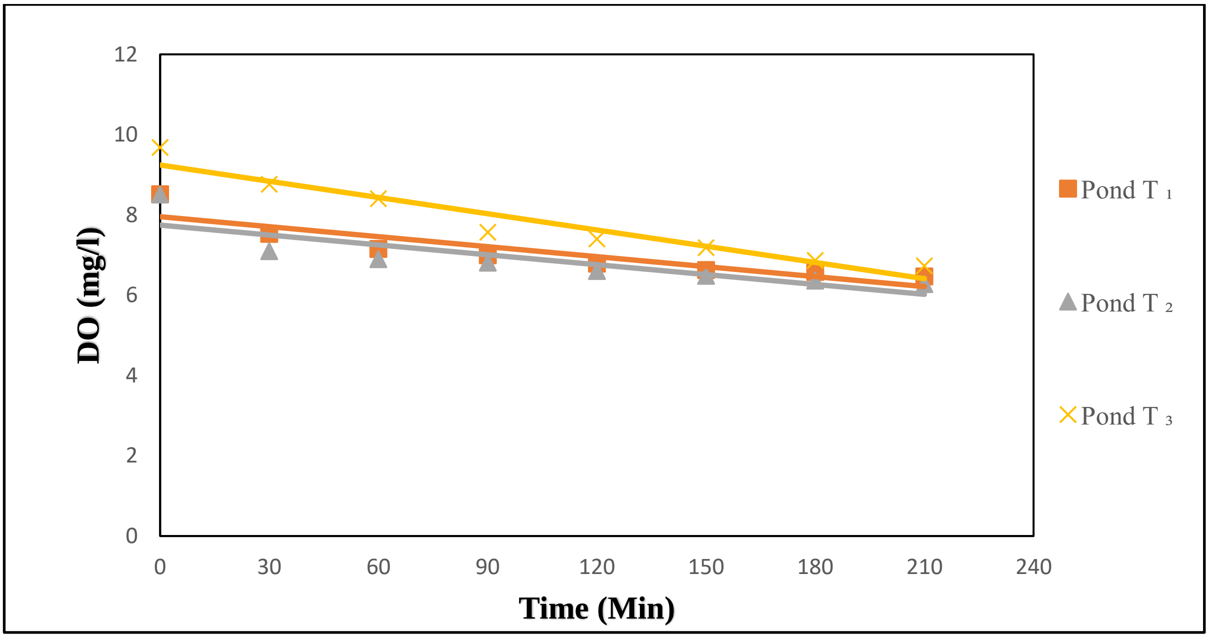

Fig. 33. Decrease of dissolved oxygen content during night time (Three tier perforated tray aerators)

the water temperature was recorded as 31 °C in all three ponds. The DO content initially recorded were 8.52 mg/l, 8.51 mg/l and 9.68 mg/l in ponds T_1, T_2 and T_3 individually. During the experimental period it was observed that the dissolved oxygen content decreased gently until it reached the final values of 6.47 mg/l, 6.28 mg/l and 6.73 mg/l in the above ponds respectively. Decrease in dissolved oxygen content of the pond water shown in the table 11 and graphically depicted in the Fig.33.

4.18.7. Dissolution of oxygen using vertical perforated cylindrical aerators during day time

Vertical perforated cylindrical aerators have been used to carry out the experiments in three ponds such as V_1, V_2 and V_3 during day time to find out the dissolution of oxygen in pond water. In the present study initial measured water temperature was 29 °C in all three ponds. Initially dissolved oxygen content in the pond water were 6.60 mg/l, 6.43 mg/l and 6.57 mg/l in above ponds respectively. By using vertical perforated cylindrical aerators initially DO concentration of pond water increased slowly during the experimental period and finally it reached the values of 8.00 mg/l, 8.04 mg/l and 8.03 mg/l in the above ponds correspondingly. Rise in dissolved oxygen content of the pond water is shown in table 12 and represented graphically in the Fig.34.

4.18.8. Dissolution of oxygen using vertical perforated cylindrical aerators during night time

Experiments have been carried out during night time to find out the dissolution of oxygen in pond water using vertical perforated cylindrical aerators. Initially the pond water temperature measured was 30 °C in all three ponds. At the beginning dissolved oxygen content

Table 12. Increase of dissolved oxygen content in the ponds water during day time (Vertical perforated cylindrical aerators)

Time (Min)	Pond V_1 DO measured (mg/l)			Pond V_2 DO measured (mg/l)			Pond V_3 DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	6.64	6.57	6.60	6.58	6.28	6.43	6.57	6.58	6.57
30	7.43	7.31	7.37	7.31	7.49	7.40	7.31	7.31	7.31
60	7.51	7.32	7.41	7.41	7.49	7.45	7.32	7.41	7.36
90	7.50	7.58	7.54	7.50	7.51	7.50	7.58	7.50	7.54
120	7.40	7.77	7.58	7.80	7.86	7.83	7.77	7.80	7.78
150	7.93	7.62	7.77	7.92	7.91	7.91	7.62	7.92	7.77
180	7.80	7.87	7.83	7.87	8.03	7.95	7.87	7.87	7.87
210	7.98	8.03	8.00	8.03	8.05	8.04	8.03	8.03	8.03

Table 13. Decrease of dissolved oxygen content in the ponds water during night time (Vertical perforated cylindrical aerators)

Time (Min)	Pond V_1 DO measured (mg/l)			Pond V_2 DO measured (mg/l)			Pond V_3 DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	10.23	10.31	10.27	10.37	10.59	10.48	10.31	10.37	10.34
30	9.09	9.04	9.06	8.80	8.90	8.85	9.04	8.80	8.92
60	8.39	8.37	8.38	8.17	8.04	8.10	8.37	8.17	8.27
90	8.20	7.99	8.09	7.77	7.74	7.75	7.99	7.77	7.88
120	7.80	7.20	7.50	7.73	7.65	7.69	7.20	7.73	7.46
150	7.97	7.80	7.88	7.51	7.42	7.46	7.80	7.51	7.65
180	7.78	7.68	7.73	7.51	7.47	7.49	7.68	7.51	7.59
210	7.68	7.61	7.64	7.41	7.38	7.39	7.61	7.41	7.51

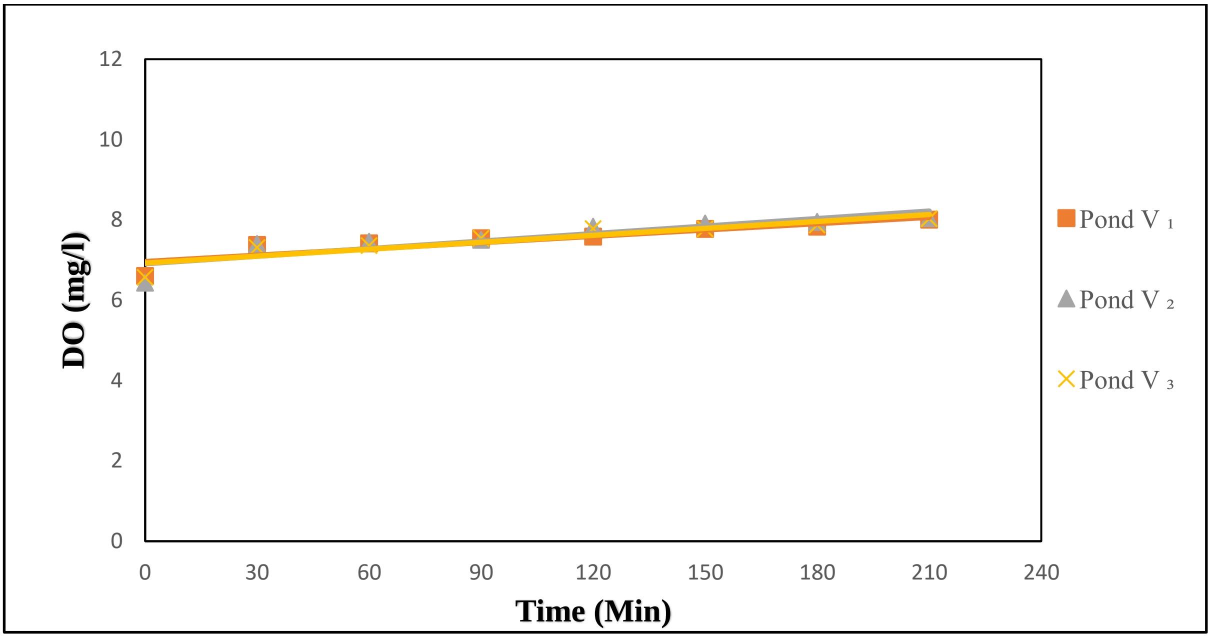

Fig. 34. Increase of dissolved oxygen content during day time (Vertical perforated cylindrical aerators)

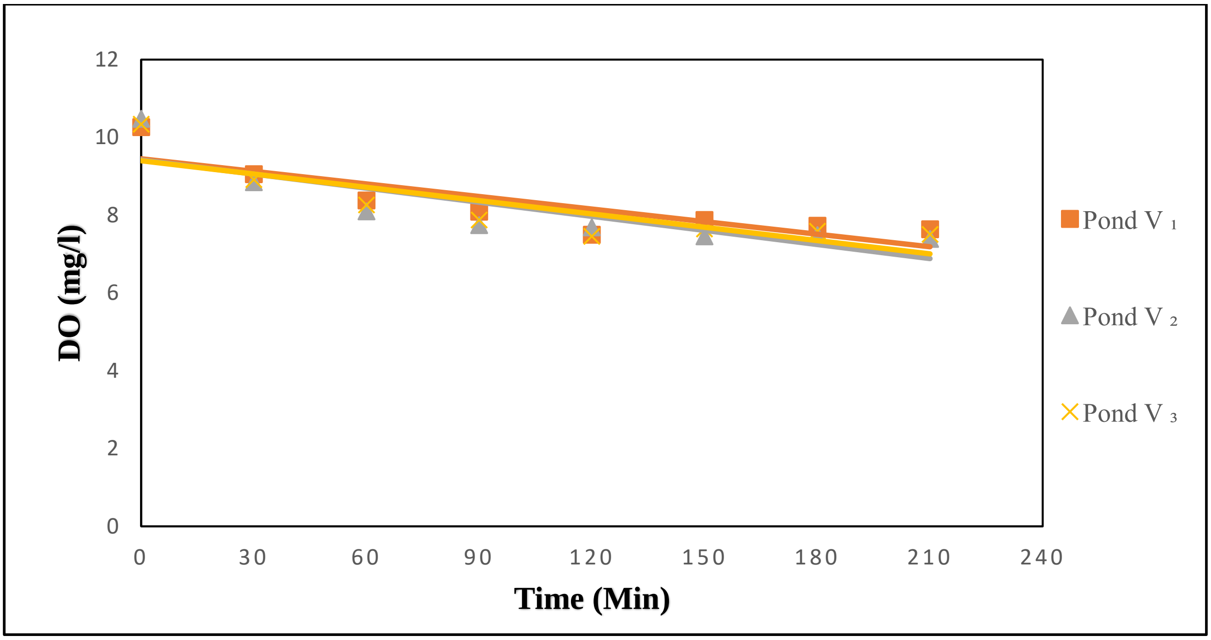

Fig. 35. Decrease of dissolved oxygen content during night time (Vertical perforated cylindrical aerators)

observed in the ponds water were 10.27 mg/l, 10.48 mg/l and 10.34 mg/l in ponds V_1, V_2 and V_3 individually. It was noticed that during the study period the dissolved oxygen content decreased gently until it reached the final values of 7.64 mg/l, 7.39 mg/l and 7.51 mg/l in the above ponds respectively. Decrease in dissolved oxygen content of the pond water is presented in the table 13 and depicted graphically in the Fig.35.

4.18.9. Dissolution of oxygen using cascading wooden plank aerators during day time

Experiments were carried out in triplicate as C_1, C_2 and C_3 during day time using cascading wooden plank aerators**.** In the beginning of the study ponds water temperature recorded was 29 °C in all three ponds. The dissolved oxygen content in the ponds water were observed as 6.32 mg/l, 6.47 mg/l and 6.45 mg/l in ponds C_1, C_2 and C_3 separately in the beginning. The dissolved oxygen content increased gradually and finally it reached the values of 7.99 mg/l, 7.79 mg/l and 7.93 mg/l in the above ponds respectively. Increase in dissolved oxygen content of the ponds water is presented in the table 14 and represented graphically in the Fig.36.

4.18.10. Dissolution of oxygen using cascading wooden plank aerators during night time

Experiments have also been carried out to find out the dissolution of oxygen in ponds water using cascading wooden plank aerators. Initially the ponds water temperature recorded was 30 °C in all three ponds. The DO content initially measured were 9.37 mg/l, 10.22 mg/l and 9.68 mg/l in ponds C_1, C_2 and C_3 respectively. The dissolved oxygen content decreased gently before reached the final values of 7.18 mg/l, 7.84 mg/l and 7.57 mg/l in above ponds

Table 14. Increase of dissolved oxygen content in the ponds water during day time (Cascading wooden plank aerators)

Time (Min)	Pond C_1 DO measured (mg/l)			Pond C_2 DO measured (mg/l)			Pond C_3 DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	6.30	6.35	6.32	6.26	6.69	6.47	6.40	6.50	6.45
30	6.53	6.61	6.57	6.47	6.61	6.54	6.57	6.69	6.63
60	6.80	7.12	6.96	6.74	6.83	6.78	6.87	7.08	6.97
90	7.13	7.77	7.45	7.56	7.62	7.59	7.61	7.64	7.62
120	7.68	7.71	7.69	7.71	7.47	7.59	7.65	7.68	7.66
150	7.71	7.84	7.77	7.64	7.79	7.71	7.73	7.86	7.79
180	7.73	8.03	7.88	7.66	7.79	7.72	7.85	7.85	7.85
210	7.80	8.18	7.99	7.79	7.79	7.79	7.91	7.95	7.93

Table 15. Decrease of dissolved oxygen content in the ponds water during night time (Cascading wooden plank aerators)

Time (Min)	Pond C_1 DO measured (mg/l)			Pond C_2 DO measured (mg/l)			Pond C_3 DO measured (mg/l)		
	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)	S_1	S_2	Avg. (mg/l)
0	9.30	9.45	9.37	10.15	10.30	10.22	9.63	9.74	9.68
30	9.09	9.04	9.06	9.80	9.76	9.78	9.23	9.14	9.18
60	8.29	8.17	8.23	9.09	8.99	9.04	8.70	8.63	8.66
90	7.80	7.20	7.50	8.71	8.66	8.68	8.34	8.24	8.29
120	7.78	7.68	7.73	8.53	8.49	8.51	8.04	7.98	8.01
150	7.54	7.49	7.51	8.20	8.11	8.15	7.78	7.78	7.78
180	7.30	7.33	7.31	7.97	7.87	7.92	7.68	7.66	7.67
210	7.23	7.13	7.18	7.81	7.87	7.84	7.58	7.57	7.57

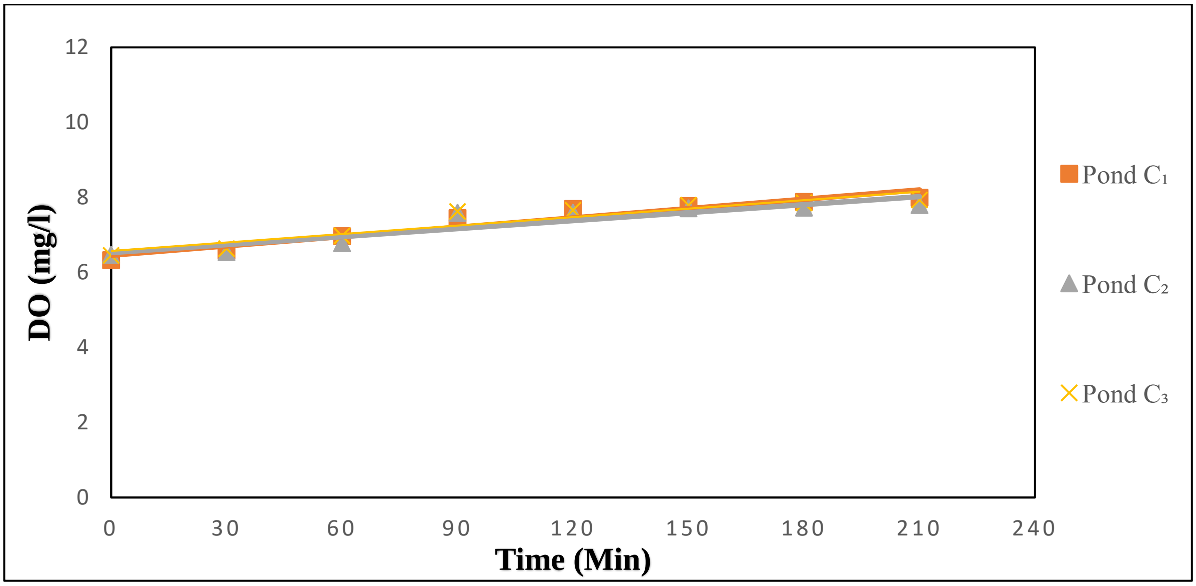

Fig. 36. Increase of dissolved oxygen content during day time (Cascading wooden plank aerators)

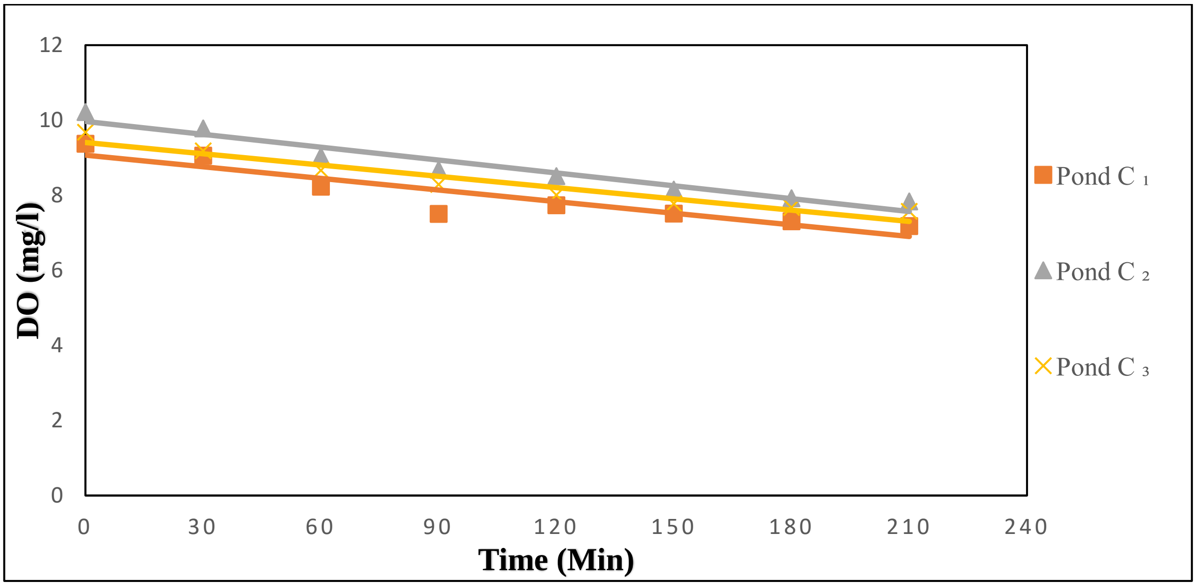

Fig. 37. Decrease of dissolved oxygen content during night time (Cascading wooden plank aerators)

respectively. Decrease in dissolved oxygen content of the pond water shown in the table 15 and graphically depicted in the Fig.37.

DISCUSSION

V. DISCUSSION

Dissolved oxygen is the single most important water quality parameter which makes shrimp or fish survive in the water and makes aquaculture production possible with high stocking and feeding rates. Maintaining optimum dissolved oxygen level in pond water for high production of shrimp or fish, maximum profitability in intensive aquaculture system are not just possible without proper aeration. Aeration can increase the carrying capacity of an aquaculture system. Oxygen is essential for the production of all species of fish and shellfish. Aeration not only increase the dissolved oxygen concentration but also help for thorough mixing and distribution of oxygen, aid in content of animal and feed waste keeping pond bottom clean and decrease risk of disease. Small aerators are widely used in fisheries to improve dissolved oxygen concentration and to effect water circulation in fish holding tanks and in ponds. With this objective, few conventional aerators were designed and fabricated. Using these fabricated aerators experiments were conducted in the ponds to check their efficiency of transferring oxygen.

5.1. Efficiency of the aerator

Aeration performance testing is important in selecting design features to provide cost effective yet efficient aquaculture pond aerators. Aerators increase the interfacial area between air and water, thus enhancing the oxygen transfer and simultaneously provide water circulation which prevents the stratification in the water body (Boyd and Martinson, 1984). Paddle wheel aerators and propeller aspirator pumps are most widely used to increase the dissolved oxygen concentration in the pond water (Boyd, 1998).

5.2. Without using aerators

Experiments were carried out in triplicate as W_1, W_2 and W_3. The pond water was initially deoxygenated and DO content measured were 0.43 mg/l, 0.43 mg/l and 0.50 mg/l in the above ponds respectively. In the three ponds, DO was measured after three hours and finally it reached the values of 4.20 mg/l, 4.15 mg/l and 4.16 mg/l in the above ponds respectively. The overall oxygen-transfer coefficient ($K_L a_T$) values obtained were 0.258 h^{-1}, 0.24 $h^{-1}$and 0.21 h^{-1} respectively. Standard Oxygen Transfer Rate (SOTR) in above ponds were 0.024 kg O_2/h, 0.023 kg O_2/h and 0.020 kg O_2/h individually. There is no much variation in overall oxygen-transfer coefficient and SOTR values were observed in the above ponds.

5.3. Vertical perforated cylindrical aerators

After deoxygenated the ponds water initially, the DO measured were 0.33 mg/l, 0.10 mg/l and 0.18 mg/l in ponds V_1, V_2 and V_3 respectively. After reoxygenated the pond water using above aerators for a duration of three hours the DO reached 8.07 mg/l, 7.76 mg/l and 7.9 mg/l respectively in the above ponds. From the results, it was noticed that aerator at the pond V_1 displays better ($K_L a_T$) and SOTR value when compared to the aerators at V_2 and V_3 ponds.

5.4. Three tier perforated tray aerators

The ponds water was deoxygenated in the beginning and DO content measured were 0.48 mg/l, 0.35 mg/l and 0.40 mg/l in ponds T_1, T_2 and T_3 respectively. The above aerators were turned on for a duration of three hours and ponds water was increased in DO content and finally it reached the values of 8.52 mg/l, 8.32 mg/l and 8.40 mg/l in above ponds respectively. The experimental results shows that the pond T_1 displays better ($K_L a_T$) and SOTR value when compared to T_2 and T_3 ponds aerators.

5.5. Rotating wheel aerators

Experiments were carried out in triplicate as R_1, R_2 and R_3. The ponds water was initially deoxygenated and DO content measured were 0.12 mg/l, 0.25 mg/l and 0.40 mg/l in the above ponds. The DO content was measured after three hours and finally it reached the values of 7.40 mg/l, 7.36 mg/l and 7.32 mg/l in the above mentioned ponds respectively. From the results, it was observed that the aerator at the pond R_1 shows better ($K_L a_T$) and SOTR value compared to R_2 and R_3 ponds aerators.

5.6. Cascading wooden plank aerators

The DO content of the ponds water were measured as 0.03 mg/l, 0.24 mg/l and 0.20 mg/l in ponds C_1, C_2 and C_3 respectively. The increased value of DO measured after three hours of aeration were 7.42 mg/l, 7.21 mg/l and 7.14 mg/l. From the results, it was detected that the pond C_1 shows better ($K_L a_T$) and SOTR value tracked by C_2 and C_3 ponds respectively.

The performance of fabricated aerators have been tested by measuring the increasing dissolved oxygen level in the experimental cement ponds after dropping the dissolved oxygen to below 0.5 mg/l. At the beginning of the experiment, the dissolved oxygen level increased sharply and then slowly until it reached the final value. The increase of DO content in the pond water shows the similar trend from all the aerators. It was concluded that vertical perforated cylindrical aerator shows better ($K_L a_T$) and SOTR value followed by three tier perforated tray aerator, rotating wheel aerator and cascading wooden plank aerator respectively. The more increasing in the dissolved oxygen content level may be the higher contacting area between water and air as well as the smaller bubbles produced and raised in the air in vertical perforated cylindrical aerator. The efficiency of aerator depends on the amount of area of contact between air and water, which is controlled primarily by the size of the water drop or air bubble.

Boyd and Ahmad (1987) have tested large number of electric aerators such as paddle wheel aerator, propeller-aspirator-pump, vertical pump, pump sprayer and diffused-air to check the oxygen transfer efficiency. The SOTR and SAE values were ranging from 0.6 to 23.2 kg O_2/h and 0.7 to 3.0 kg O_2 kW/h respectively. Boyd and Ahmad (1987) have also tested several tractor-powered pump sprayer and paddle wheel aerators. The SOTR values ranged from 7.8 to 73.8 kg O_2/h respectively.

Omofunmi *et al*. (2016) have developed low cost prototype paddle wheel aerator. The performance test was carried out and it showed that the overall oxygen transfer co-efficient (K_L a) as high as 8.19 $h^{-1}$and SOTR and SAE ranged from 1.1 – 1.2 kg O_2/h and 1.1 – 1.3 kg O_2 kW/h respectively. Boyd (1990) reported that the SOTR and SAE for twenty four types of the paddle wheel aerators ranged from 1.9 – 8.5 kg O_2/h and 1.2 – 5.2 kg O_2 kW/h respectively. Ahmad and Boyd (1988) tested several designs of paddle wheel aerator and reported that the out of all aerators, 91 cm diameter paddle wheel with triangular paddles aerator showed the highest SAE of 2.96 kg O_2 kW/h. The SOTR and SAE for six paddle wheel aerators ranged from 5.2 – 18.5 kg O_2/h and 2.6 – 3.0 kg O_2 kW/h respectively as reported by Boyd and Ahmad (1987) and Moore and Boyd (1992).

Boyd and Martinson (1984) conducted the experiments on propeller-aspirator pump aerators and found that the SAE ranged between 1.73 and 1.91 kg O_2 kW/h. Kumar *et al*. (2010) also reported that the maximum SOTR and SAE values were 0.15 kg O_2/h and 0.42 kg O_2 kW/h respectively for propeller aspirator pump aerator.

Many combinations of paddle wheel diameter, speed and paddle depth had SAE values of 2.25 kg O_2 kW/h or higher. These SAE values are superior to values of 0.85-1.64 kg O_2 kW/h as reported by Boyd and Ahmad (1987) and Ruttanagosrigit *et al*. (1991) for 2-hp paddle wheel aerators made in Taiwan. Boyd and Ahmad (1987) evaluated six electric paddle wheel aerators which covered a wide range of SAE values from 1.16-2.13 kg O_2 kW/h. Boyd and Martinson (1984) reported that SAE values for a diffused-air aeration system as 1.08 kg O_2 kW/h, vertical pump surface aerators ranges between 1.34-1.41 kg O_2 kW/h and propeller-aspirator-pump aerators ranges between 1.73-1.91 kg O_2 kW/h.

Paddle wheel aerators were considered as the most efficient aerators in terms of standard aeration efficiency and circulation (Rappaport *et al*., 1976; Boyd and Ahmad, 1987; Lawson, 1995; Colt and Orwicz, 1991; Boyd, 1998).The greatest SAE (2.96 kgO_2kWh^{-1}) was achieved for a 91cm diameter paddle wheel with triangular shape as reported by Taufic and Boyd (1988). Thakre *et al.* (2008) reported that the Curved Blade Rotor showed the optimum value of K_{La} and AE were 10.33 per hour and 2.269 kg O_2/ kWh respectively. Roy *et al*. (2016) reported the maximum SOTR and SAE of 0.622 kg O_2/h and 1.0 kg O_2/kWh respectively for spiral aerator.

Pre-performance evaluation of the original and modified submersible aerator without having a provision to vary (α) and (d) was done and resulted in SAE of 0.320 kg O_2/ kWh.

Finally, the optimized value of SAE of 0.616 kg O_2/kWh was achieved. The percentage increase in efficiency after modification was 92.50 % as reported by Jayraj *et al*. (2017).

Petrille and Boyd (1984) reported that the SOTR of 26.3 kg O_2/h for a tractor-powered paddle wheel aerator tested in a 1000 m^2 pond of 1m average depth. Armstrong and Boyd (1982) tested an almost identical PTO aerator and observed the SOTR was 30.0 kg O_2/h.

Bhuyar *et al*. (2009) concluded that out of six different configurations of aerators tested, the curved blade rotor (CBR) emerged as a potential aerator. The overall oxygen transfer co-efficient (K_L a) was observed as 10.33 $hr^{-1}$and the optimum aerator efficiency (AE) was 2.269 kg O_2/kWh. Boyd and Watten (1989) and Boyd (1998) reported that a wide variation in performance of aerators in terms of standard aeration efficiency was found, viz. "Taiwanese" aerator (1.17 kg O_2 kW/h), "Japanese" aerator (1.03 kg O_2 kW/h) and Auburn University design (2.25 kg O_2 kW/h). Moulick *et al*. (2005) reported that in an optimum dynamic condition, single hub paddle wheel aerator has produced maximum SAE of 1.65 kg O_2 kW/h. Armstrong and Boyd (1982) reported that a similar paddle wheel aerator powered by a 50-kW tractor, transferred SOTR of 30 kg O_2/h.

Busch *et al*. (1984) reported that the power requirement of the tractor-powered units was directly related to the diameter of the paddle wheel drum and the paddle immersion depth. Oxygen transfer rates ranged from 6.9 to 41 kg $hr^{-1}$and increased linearly with the power requirement. The results obtained in the present study are in concurrence with result obtained by the above mentioned authors.

In aquaculture ponds, plankton not only is a key element of the food web, but also has a significant effect on the climate and the composition of the atmosphere, in particular on the amount of oxygen. Plankton consists of two different taxa: phytoplankton and zooplankton. As most plants do, phytoplankton can produce oxygen in photosynthesis when sufficient light is available, e.g., in the photic layer of the water column during the day time. The oxygen first comes to the water and eventually into the air through the surface, thus contributing to the total oxygen budget in the pond. One can expect that a decrease in the rate of the oxygen production by phytoplankton may have catastrophic consequences for life on earth, possibly resulting in mass extinction of organisms. Besides having capabilities to produce oxygen, planktonic community also depends on the oxygen availability and its confounding factors. During night time respiration of fauna and flora, decomposition of organic matter, reduction due to other gases such as methane, CO_2 and others which accumulate in the bottom bubble up and wash out the oxygen dissolved in water.

5.7. Dissolution of oxygen without using aerator during day time

At the beginning of the experiment dissolved oxygen content of water were 6.95 mg/l, 6.19 mg/l and 7.15 mg/l in ponds W_1, W_2 and W_3 respectively. The dissolved oxygen content of the pond water increased slowly during the experiment and finally it reached the values of 7.63 mg/l, 7.26 mg/l and 7.76 mg/l in the above ponds.

5.8. Dissolution of oxygen without using aerator during night time

The dissolved oxygen content in the ponds water measured in the beginning of the experiment were 8.43 mg/l, 8.58 mg/l and 8.73 mg/l in ponds W_1, W_2 and W_3 respectively. The dissolved oxygen content gradually decreased until it reaches the final values of 7.08 mg/l, 6.99 mg/l and 7.17 mg/l in the above ponds respectively.

5.9. Dissolution of oxygen using rotating wheel aerators during day time

The DO content initially measured were 6.71 mg/l, 6.66 mg/l and 6.43 mg/l in ponds R_1, R_2 and R_3 respectively. Rotating wheel aerators were used to increase the DO content of the pond water, initially DO concentration of pond water increased fastly, increased slowly for some period and finally it reached the values of 8.02 mg/l, 7.79 mg/l and 7.87 mg/l in the above ponds respectively.

5.10. Dissolution of oxygen using rotating wheel aerators during night time

The dissolved oxygen content observed in the ponds water were 9.68 mg/l, 10.16 mg/l and 10.32 mg/l in ponds R_1, R_2 and R_3 respectively in the beginning of the experiment. The dissolved oxygen content decreased gently during the study period and finally it reached the values of 7.36 mg/l, 7.37 mg/l and 7.42 mg/l in the above ponds correspondingly.

5.11. Dissolution of oxygen using three tier perforated tray aerators during day time

The dissolved oxygen content in the pond water were observed initially as 7.05 mg/l, 6.90 mg/l and 6.79 mg/l in ponds T_1, T_2 and T_3 separately. The dissolved oxygen content increased gradually during the experimental period and finally it reached the values of 8.43 mg/l, 8.48 mg/l and 8.45 mg/l in the above mentioned ponds respectively.

5.12. Dissolution of oxygen using three tier perforated tray aerators during night time

The DO content initially recorded as 8.52 mg/l, 8.51 mg/l and 9.68 mg/l in ponds T_1, T_2 and T_3 individually. During the experimental period it was observed that the dissolved oxygen content decreased gently until it reached the final values of 6.47 mg/l, 6.28 mg/l and 6.73 mg/l in the above ponds.

5.13. Dissolution of oxygen using vertical perforated cylindrical aerators during day time

Initially dissolved oxygen content of water were 6.60 mg/l, 6.43 mg/l and 6.57 mg/l in ponds V_1, V_2 and V_3 respectively. By using the vertical perforated sheet aerator DO concentration of pond water increased slowly during the experimental period and finally it reached the values of 8.00 mg/l, 8.04 mg/l and 8.03 mg/l in the above mentioned ponds respectively.

5.14. Dissolution of oxygen using vertical perforated cylindrical aerators during night time

At the beginning, dissolved oxygen content of water were 10.27 mg/l, 10.48 mg/l and 10.34 mg/l in ponds V_1, V_2 and V_3 individually. It was noticed that during the study period the dissolved oxygen content decreased gently until it reached the final values of 7.64 mg/l, 7.39 mg/l and 7.51 mg/l in the above ponds respectively.

5.15. Dissolution of oxygen using cascading wooden plank aerators during day time

The dissolved oxygen content of water were observed as 6.32 mg/l, 6.47 mg/l and 6.45 mg/l in ponds C_1, C_2 and C_3 separately in the beginning. The dissolved oxygen content increased gradually and finally it reached the values of 7.99 mg/l, 7.79 mg/l and 7.93 mg/l in the above mentioned ponds respectively.

5.16. Dissolution of oxygen using cascading wooden plank aerators during night time

The DO content initially measured were 9.37 mg/l, 10.22 mg/l and 9.68 mg/l in ponds C_1, C_2 and C_3 respectively. The dissolved oxygen content decreased gently before reached the final values of 7.18 mg/l, 7.84 mg/l and 7.57 mg/l in above ponds respectively.

Aeration with fabricated aerators increased the dissolution of oxygen levels during day time, while decrease in DO levels at night was evident. The increased oxygen dissolution during day time was probably due to congenial environmental temperatures that complimented the dissolution of oxygen in to water. While the drop in environmental temperatures during night and accelarated growth of microbial populations would have affected the dissolution of oxygen.

SUMMARY

VI. SUMMARY

An investigation was carried out at the Research and Instructional Fish Farm of the College of Fisheries, Mangaluru, to check the efficiency of low cost fabricated aerators such as three tier perforated tray aerator, vertical perforated cylindrical aerator, rotating wheel aerator and cascading wooden plank aerator and also studied its influence on dissolution of oxygen in pond water.

The results of the efficiency of the aerators are as follows

1) The overall oxygen-transfer coefficient ($K_L\ a_T$) and Standard Oxygen Transfer Rate (SOTR) without using aerator (Pond W_1) obtained were 0.252 h^{-1} and 0.024 kg O_2/h respectively.
2) Without using aerator (Pond W_2) shows overall oxygen-transfer coefficient ($K_L\ a_T$) and Standard Oxygen Transfer Rate as 0.24 h^{-1} and 0.023 kg O_2/h respectively.
3) The overall oxygen-transfer coefficient ($K_L\ a_T$) reached upto 0.210 h^{-1} and Standard Oxygen Transfer Rate reached upto 0.020 kg O_2/h respectively in pond W_3 without using aerator.
4) The overall oxygen-transfer coefficient ($K_L\ a_T$) and Standard Oxygen Transfer Rate (SOTR) of vertical perforated cylindrical aerator (Pond V_1) was recorded as 1.788 h^{-1} and 0.167 kg O_2/h respectively.
5) The Standard Oxygen Transfer Rate (SOTR) and overall oxygen-transfer coefficient ($K_L\ a_T$) of vertical perforated cylindrical aerator (Pond V_2) was recorded as 0.150 kg O_2/h and 1.602h^{-1} respectively.

6) The vertical perforated cylindrical aerator (Pond V_3) shows the overall oxygen-transfer coefficient ($K_L a_T$) and Standard Oxygen Transfer Rate (SOTR) as 1.560 h^{-1} and 0.146 kg O_2/h respectively.
7) The overall oxygen-transfer coefficient ($K_L a_T$) and Standard Oxygen Transfer Rate (SOTR) of three tier perforated tray aerator (Pond T_1) was recorded as 1.602 h^{-1} and 0.165 kg O_2/h respectively.
8) Three tier perforated tray aerator (Pond T_2) shows the overall oxygen-transfer coefficient ($K_L a_T$) as 1.518 h^{-1}. The Standard Oxygen Transfer Rate reached upto 0.156 kg O_2/h for the same aerator.
9) The overall oxygen-transfer coefficient ($K_L a_T$) and (SOTR) Standard Oxygen Transfer Rate of three tier perforated tray aerator in the pond T_3 were 1.380 h^{-1} and 0.142 kg O_2/h respectively.
10) The overall oxygen-transfer coefficient ($K_L a_T$) and (SOTR) Standard Oxygen Transfer Rate of rotating wheel aerator in the pond R_1 was calculated as 1.170 h^{-1} and 0.107 kg O_2/h respectively.
11) Rotating wheel aerator (Pond R_2) shows Standard Oxygen Transfer Rate (SOTR) and overall oxygen-transfer coefficient ($K_L a_T$) as 0.102 kg O_2/h and 1.122 h^{-1} respectively.
12) In pond R_3 by using rotating wheel aerator, the overall oxygen-transfer coefficient ($K_L a_T$) reached upto1.086 h^{-1} and (SOTR) Standard Oxygen Transfer Rate raised upto 0.099 kg O_2/h respectively.
13) The overall oxygen-transfer coefficient ($K_L a_T$) and (SOTR) Standard Oxygen Transfer Rate of cascading wooden plank aerator in the pond C_1 was 1.062 h^{-1} and 0.097 kg O_2/h respectively.

14) The overall oxygen-transfer coefficient ($K_L a_T$) reached upto 0.924 h^{-1} and (SOTR) Standard Oxygen Transfer Rate reached upto 0.084 kg O_2/h respectively after using cascading wooden plank aerator in the pond C_2.
15) Cascading wooden plank aerator (Pond C_3) shows the overall oxygen-transfer coefficient ($K_L a_T$) of 0.840 h^{-1} and (SOTR) Standard Oxygen Transfer Rate value of 0.077 kg O_2/h.

The present experiments were carried out using the fabricated aerators with the help of a pump. Considering the cost, aeration cost is the third largest expenditure in intensive aquaculture system after post larvae and feed cost, representing about 15% of total production cost. The cost of mechanical aerators is more and it required more operational and maintenance cost. The present study results suggested that the above conventional fabricated aerators may be used to increase the dissolved oxygen content in the smaller fish ponds.

The salient findings of the dissolution of oxygen into the pond water are as follows

16) At the beginning of the experiment dissolved oxygen content of water were 6.95 mg/l, 6.19 mg/l and 7.15 mg/l in ponds W_1, W_2 and W_3 respectively. During day time without using aerators dissolution of oxygen in pond water increased and finally it reached the values of 7.63 mg/l, 7.26 mg/l and 7.76 mg/l in the above ponds.
17) The dissolved oxygen content of the ponds water were measured in the beginning of the experiment as 8.43 mg/l, 8.58 mg/l and 8.73 mg/l in ponds W_1, W_2 and W_3 respectively. Without using the aerators during night time, dissolved oxygen content gradually decreased until it reaches the final values of 7.08 mg/l, 6.99 mg/l and 7.17 mg/l in the above ponds respectively.

18) The DO content of water was initially recorded as 6.71 mg/l, 6.66 mg/l and 6.43 mg/l in ponds R_1, R_2 and R_3 respectively. Rotating wheel aerators were used during day time the dissolution of oxygen concentration in the pond water increased slowly and finally it reached the values of 8.02 mg/l, 7.79 mg/l and 7.87 mg/l in the above ponds respectively.

19) The dissolved oxygen content of water were observed as 9.68 mg/l, 10.16 mg/l and 10.32 mg/l in ponds R_1, R_2 and R_3 respectively in the beginning of the experiment. Rotating wheel aerators were turned on during night time, dissolved oxygen content decreased gently during the study period and finally it reached the values of 7.36 mg/l, 7.37 mg/l and 7.42 mg/l in the above ponds correspondingly.

20) The dissolved oxygen content of the water were observed initially as 7.05 mg/l, 6.90 mg/l and 6.79 mg/l in ponds T_1, T_2 and T_3 separately. Using three tier perforated tray aerators during day time dissolution of oxygen content increased gradually during the experimental period and finally it reached the values of 8.43 mg/l, 8.48 mg/l and 8.45 mg/l in the above mentioned ponds respectively.

21) The DO content initially recorded during the study period were 8.52 mg/l, 8.51 mg/l and 9.68 mg/l in ponds T_1, T_2 and T_3 individually. Three tier perforated tray aerators were turned on during night time, dissolution of oxygen content decreased gently until it reached the final values of 6.47 mg/l, 6.28 mg/l and 6.73 mg/l in the above ponds.

22) Initially dissolved oxygen content of water were 6.60 mg/l, 6.43 mg/l and 6.57 mg/l in ponds V_1, V_2 and V_3 respectively. Using vertical perforated cylindrical aerators during day time dissolution of oxygen concentration in pond water increased slowly during the experimental period and finally it reached the values of 8.00 mg/l, 8.04 mg/l and 8.03 mg/l in the above mentioned ponds respectively.

23) At the beginning, dissolved oxygen content of water were observed as 10.27 mg/l, 10.48 mg/l and 10.34 mg/l in ponds V_1, V_2 and V_3 individually. During night time dissolution of oxygen content decreased gently until it reached the final values of 7.64 mg/l, 7.39 mg/l and 7.51 mg/l in the above ponds respectively.
24) The dissolved oxygen content of water were observed as 6.32 mg/l, 6.47 mg/l and 6.45 mg/l in ponds C_1, C_2 and C_3 separately in the beginning. Using cascading wooden plank aerators during day time dissolution of oxygen content increased gradually and finally it reached the values of 7.99 mg/l, 7.79 mg/l and 7.93 mg/l in the above ponds respectively.
25) The DO content initially measured were 9.37 mg/l, 10.22 mg/l and 9.68 mg/l in ponds C_1, C_2 and C_3 respectively. The cascading wooden plank aerators were turned on during night time, dissolution of oxygen content decreased gently before reached the final values of 7.18 mg/l, 7.84 mg/l and 7.57 mg/l in above ponds respectively.

Aeration with fabricated aerators increased the dissolution of oxygen levels during day time, while decrease in DO levels at night was evident. The increased oxygen dissolution during day time was probably due to congenial environmental temperatures that complimented the dissolution of oxygen in to pond water. While the drop in environmental temperatures during night and accelerated growth of microbial populations would have affected the dissolution of oxygen.

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ABSTRACT

VIII. ABSTRACT

In the present study, four different types of aerators were designed and fabricated such as three tier perforated tray aerator, cascading wooden plank aerator, rotating wheel aerator and vertical perforated cylindrical aerator. Experiments have been carried out to check the efficiency of the above aerators and also dissolution of oxygen in pond water during day and night. These experiments have been conducted at the Research and Instructional Fish Farm of the College of Fisheries, Mangaluru. Three uniform square shaped cement ponds of the size (5 × 5 × 1 m) without soil base were selected for conducting the experiments. These fabricated aerators performance evaluation was tested in triplicate using Unsteady-State Test Procedure. Results of these experiments showed that the Standard Oxygen Transfer Rate (SOTR) of vertical perforated cylindrical aerator (Ponds V_1, V_2 and V_3) were recorded as 0.167 kg O_2/h, 0.150 kg O_2/h and 0.146 kg O_2/h respectively. Three tier perforated tray aerator (Ponds T_1, T_2 and T_3) shows the SOTR as 0.165 kg O_2/h, 0.156 kg O_2/h and 0.142 kg O_2/h respectively. In R_1, R_2 and R_3 ponds by using rotating wheel aerator, the SOTR was raised up to 0.107 kg O_2/h, 0.102 kg O_2/h and 0.099 kg O_2/h respectively. The SOTR of cascading wooden plank aerator in the ponds C_1, C_2 and C_3 were 0.097 kg O_2/h, 0.084 kg O_2/h and 0.077 kg O_2/h respectively. From the above results it was noticed that the vertical perforated cylindrical aerator shows better SOTR value followed by three tier perforated tray aerator, rotating wheel aerator and cascading wooden plank aerator. Aeration by using the above aerators increases the dissolution of oxygen during day time, while decrease in dissolved oxygen levels at night was evident. The increased oxygen dissolution during day time was probably due to congenial environmental temperature that complimented the dissolution of oxygen in to pond water. While the drop in environmental

temperature during night and accelerated growth of microbial populations would have affected the dissolution of oxygen.

Keywords: Dissolved oxygen, Fabricated aerators, Dissolution of oxygen, Standard Oxygen Transfer Rate