

CERTIFICATION OF APPROVAL

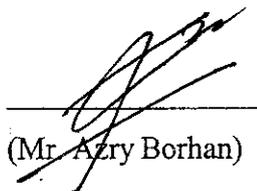
**The Effect Study of Absorption Coefficient and Oxygenation Capacity in UTP
lakes.**

by

Firdaus Bin Ahmad

A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

Approved by,



(Mr. Azry Borhan)
Main Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

Jun 2004

7
QD
181
F522
2004
1. Oxidation
2. Acid mine drainage
3. CHE -- thesis

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the project submitted, that the original work is on my own doing except as specified in the references and acknowledgements, and the original work contain herein have not been undertaken or done by unspecified sources or persons.



FIRDAUS BIN AHMAD

ABSTRACT

This project is to study the effect of overall transfer coefficient, K and oxygenation capacity, R on UTP lakes. It contains 5 objectives which are, to study the non steady state condition of UTP lakes samples, the effect of different air flow rate used on K and R values, the effect of different depth used in aeration tank on K and R values, the effect of different waste material on K and R values and finally the effect of different diffuser arrangement on K and R values. Transfer coefficient and oxygenation capacity are important in any aeration study since they are the parameters to indicate the oxygen transfer and oxygen dissolve behavior in any water sample.

A key water quality parameter common to each is dissolved oxygen or the transfer of gases into or out of water. As a result, aeration can be critical in maintaining good water quality conditions for all these process. Aeration is a process that implies bringing water and air into contact to facilitate oxygen transfer and thus aeration unit is the equipment used to observe these processes.

The methodology of experiment is to aerate the water samples in aeration tank (Armfield Unit w10) with specific procedures and disciplines. Since the project is relevant to the aeration, student has to study the aeration itself. The aeration definition, applications, equipments, type of aerators and limitations are considered study materials. But to be specific, the experiment only deals with non porous diffuser (sparger tube) which is default diffuser of the equipment.

At the end of experiments it was found that the K value for lake A (Behind the UTP mosque) is higher than lake B (Near the Ruby block) for all objectives. R value is proportionally to K value if all variables kept constant, but R value will be most effected if the experiment is conducted at difference average temperature. In overall, lake A give better aeration result compared to lake B, but the differences results does not make any significant effect in any industries applications since the difference is very small.

ACKNOWLEDGMENT

In the name of Allah, The Most Merciful.

I would like to express my special gratitude to my supervisor, Mr. Azry Borhan, the Final Year Research Project Coordinator, Miss Yuliana Bt Yuhana and the Head of Chemical Engineering Department, Dr. Hilmi Bin Mukhtar for their guidance, suggestions, attentions, concerns and support during my research work throughout the project execution and completion period.

Special thanks to the laboratory technicians, Mr Zaaba and his colleagues, Mr Affendi, Mr Firdaus, Mr Sahar and Mr Mahathir for the assistance and trust of handling laboratory equipment during the experimental work.

It is pleasure for me to thank to my beloved parent, my father, Dr. Ahmad Bin Hashim, my mother, Pn. Ustaniah Hj Bustami, and my siblings Saiful Aswat and Taufiq for their understanding and support, and not to forget my fellow comrades and classmates for their tolerations, consideration, and co-operations all this while.

I acknowledge with greatest appreciation to other individual and groups not mentioned above who gave me such tremendous motivation directly or indirectly in completing this project. I sincerely apologize for all the problems involuntarily caused. Thank you.

TABLE OF CONTENT

CERTIFICATION OF APPROVAL.		i
CERTIFICATION OF ORIGINALITY.		ii
ABSTRACT.		iii
ACKNOWLEDGEMENTS.		iv
TABLE OF CONTENTS.		v
LIST OF FIGURES.		vii
LIST OF TABLES.		viii
ABBREVIATION AND NOMENCLATURES.		ix
CHAPTER 1	INTRODUCTION.	1
	1.1 Background of Study.	1
	1.2 Problem Statement.	3
CHAPTER 2	OBJECTIVE AND SCOPE OF STUDY.	4
CHAPTER 3	LITERATURE REVIEW AND THEORY.	6
	3.1 Aeration in General.	6
	3.2 Purpose of Aeration.	6
	3.3 Definition of Aeration.	7
	3.4 Type of Aerators.	7
	3.5 General Theory of Aeration.	11
	3.6 Theory Applied to achieve Coefficient. Absorption, K and Oxygenation Capacity. of A System, R.	12
	3.7 Description of Diffused Air System.	13

	3.8	Fine and Coarse Bubbles Diffuser System.	14
CHAPTER 4		METHODOLOGY/PROJECT WORK.	17
	4.1	Equipment/tools Required for this Project.	17
	4.2	Description of The Unit.	17
	4.3	Procedures Identification/Experiment.	
		Procedures.	19
	4.4	Summary of Test Method.	22
CHAPTER 5		RESULT AND DISCUSSION.	25
	5.1	Findings and Discussions.	25
	5.2	Further Related Discussion.	40
CHAPTER 6		CONCLUSION AND RECOMMENDATION.	42
REFERNCES			44
APPENDICES			47
		APPENDICES A : EXPERIMENTAL RAW DATA	
		APPENDICES B : EXPERIMENTAL CALCULATION	
		APPENDICES C : TABLE OF CORRECTION FACTOR	

LIST OF FIGURES

- Figure 3.1 : Spray aerator
- Figure 3.2 : Waterfall or Multiple Tray Aerators
- Figure 3.3 : Cascade Aerator
- Figure 3.4 : Fine Bubbles and Coarse Bubbles Identification
- Figure 4.0 : Sketch for Experiment Set Up
- Figure 4.1 : Armfield Aeration Unit
- Figure 4.2 : Oxygen Probe diagram
- Figure 5.1 : Unsteady State Condition for Lake A and B
- Figure 5.2 : Different Airflow Rate for Lake A
- Figure 5.3: Different Airflow rate for Lake B
- Figure 5.4: Significant of R Value with Temperature
- Figure 5.5: Different water Depth of Lake A
- Figure 5.6: Different water Depth of Lake B
- Figure 5.7 : Comparison on Slope value Between wastewater (lake A) and Clean water
- Figure 5.7.1 : Sparger tube diffuser
- Figure 5.7.2 : Single Air stone diffuser
- Figure 5.8 : Comparison of slope for different diffuser arrangement of Lake A
- Figure 5.9 : Comparison of slope for different diffuser arrangement of Lake B

LIST OF TABLES

- Table 5.0 : BOD Testing Result For Lake A and Lake B
- Table 1.0: Non steady State Condition (Lake A) – Flowrate 4 L/Min
- Table 1.1 : Different Air Flowrate (Lake A) – 4 L/Min
- Table 1.2 : Different Air Flowrate (Lake A) – 8 L/Min
- Table 1.3 : Different Air Flowrate (Lake A) – 12 L/Min
- Table 1.4 : Different Depth (Lake A) – 100mm
- Table 1.5 : Different Depth (Lake A) – 200mm
- Table 1.6 : Different Depth (Lake A) – 300mm
- Table 1.7 : Diference Diffuser Arrangement (Lake A) – single airstone
- Table 2.0 : Non Steady State Condition (Lake B) – Flowrate 4 L/Min
- Table 2.1 : Different Flowrate (Lake B) – 4 L/Min
- Table 2.2 : Different Flowrate (Lake B) – 8 L/Min
- Table 2.3 : Different Flowrate (Lake B) – 12 L/Min
- Table 2.4 : Different Depth (Lake B) – 100mm
- Table 2.5 : Different Depth (Lake B) – 200mm
- Table 2.6 : Different Depth (Lake B) – 300mm
- Table 2.7 : Diference Diffuser Arrangement (Lake B) – Single Airstone
- Table 3.0 : Diference waste material (clean water)

ABBREVIATIONS AND NOMENCLATURES

ABBREVIATIONS

DO	Dissolve Oxygen
BOD	Biological Oxygen Demand
OTE	Oxygen Transfer Efficiency
SOTE	Standard Oxygen Transfer Efficiency
UTP	Universiti Teknologi PETRONAS

NOMENCLATURES

K	Transfer Coefficient
R	Oxygentaion Capacity
Cs	Saturation Concentration
F	Temperature Correction Factor
O ₂	Oxygen
V	Voltage
°C	Degree Celcius
mm	Milimeter
m	Meter
hr	Hour
g	Gram
Na ₂ SO ₃	Natrium Sulphite
CoCl ₂ .6H ₂ O	Cobultus Chloride
H ₂ O	Hidrogen dioxide
H ₂ S	Hidrogen Sulphite
CO ₂	Carbon Dioxide
α	Alpha factor
mg	Miligram
L	Liter
min	Minute

CHAPTER 1

INTRODUCTION

1.1 Background of Study

UTP lakes are artificial lakes which originated from abandoned mines. In the early of 19th century, Tronoh was recognized as the mining areas. A lot of mines were farmed by locals and foreign to take out the precious resources such as gold and tin. By geography, the sandy type land which occupied the area allows the mining work to be happened. Until the mid of 50's, the resources were subsided and slowly as the years passed by the mines were abandoned.

These abandoned mines were finally become artificial lakes. There are 5 artificial lakes in UTP. Their existing contributes to the beautiful scenery for the whole UTP landscape. The largest lake was located behind the UTP mosque. This lake is commercially used as water-recreation center for UTP students. Many activities held such as kayaking and fishing competition. The commercial values of that lake are mostly rely on its size and its location which is suitable for people to strolling aside and reachable for the eyes to see the whole lake scenery. It is such fabulous and mesmerizing view with wavy yellowish water and the big green trees surround the lake.

For other 4 lakes, two are located behind Propana's block, one is located near the main road and another one located beside Ruby's block. Different perspectives are pointed to these lakes. They are surrounded by the watery, thick bushes. Basically, these four lakes are considered as restricted area because the bushes may cause harm to those who passing there. Many poisonate creatures such as snakes and insects inhabit the lakes area. These lakes do not produce water for public used. They contained a lot poisons materials such as hydrogen sulphide, carbon dioxide and methane. [Mohd Redzuan Mansor and Abdul Malik, Engineering Team Project : Water Treatment; 2002].

Oxygen transfer or aeration plays an important role in biological wastewater treatment processes. For example, effective operation of the activated sludge process requires an adequate supply of dissolved oxygen to support the microbial oxidation processes that occur in the reservoirs or lakes such UTP have. The oxygen transfer process is the primary use of electrical energy in the secondary treatment process and represents a significant capital cost as well. Therefore, significant attention has been paid to the design and operation of aeration systems with lower capital cost and higher aeration efficiency in the wastewater treatment processes.

This study is to perform aeration test on the UTP lake sample and to find the transfer coefficient, K and oxygenation capacity, R . The experiment will be conducted in the chemical laboratory by using Aeration Equipment Armfield Unit W10. Submerged aeration systems are used in lakes, reservoirs, and wastewater treatment facilities to increase dissolved oxygen (DO) levels and promote water circulation. Submerged diffusers release air or pure oxygen bubbles at depth, producing a free, turbulent bubble-plume that rises to the water surface through buoyant forces at roughly an 11° angle of spreading. The ascending bubble plume entrains water, causing vertical circulation and lateral surface spreading. Oxygen transfers to the water across the bubble interfaces as the bubbles rise from the diffuser to the water surface. Oxygen transfer also occurs across the air-water interface at the free surface due to turbulence induced by bubble-plume motion and water circulation.

It should be bear in mind that this study is basically aeration based and the result produced will acknowledge us how effective the aeration unit in giving the significant value toward the UTP lake samples.

1.2 Problem Statement

1.2.1 Problem identification

Water quality management is vitally important for many applications, particularly waste water treatment, lake and reservoir management, aquaculture, environmental management, biofiltration and water treatment. A key water quality parameter common to each is dissolved oxygen or the transfer of gases into or out of water. As a result, aeration can be critical in maintaining good water quality conditions for all these processes. Aeration is a process that implies bringing water and air into contact to facilitate oxygen transfer and thus aeration unit is the equipment used to observe these processes.

1.2.2 Significant of the Project

The project carried out has significant effects for those who going to study water treatment of UTP lakes and how the water is possibly used domestically or commercially in the future. Basically, all the data, calculation, and discussion in this project will be used as a standard parameter for researchers to make their own studies about the lakes in order to implement any suitable treatment method or any appropriate technology. Besides, this project result will be used to measure, evaluate and to compare any experimental result which come out from chemical engineering students who's going to perform Aeration Experiment in their Chemical Engineering Lab 2.

CHAPTER 2

OBJECTIVE AND SCOPE OF STUDY

This project has certain objectives to be achieved. The main objective of the project is the study of absorption coefficient, K and oxygenation capacity, R under non-steady state conditions. The experiment is considered non steady state because not all the parameters involved are constant. In this case, during the experiment, the temperature decreases as the time goes by. So temperature is not constant anymore which by mean the experiment runs under non steady state condition. Besides, by using aeration unit, there are 4 other objectives that should be achieved; there are:

1. To study the effect of airflow rates on the values of K and R .
2. To study the effect of design and arrangement of diffusers on K and R values.
(using clean water as control experiment)
3. To study the effect of water depth on the K and R values.
4. To study the effect waste materials on K and R . (comparison with clean water)

Regarding to the objective of study the effect on K and R values of steady and non-steady state condition, student should apply initial and final oxygen content test to compare the dissolve oxygen value.

Since the project is relevant to the aeration, the student has to study the aeration itself. The aeration definition, mechanism, applications, equipments, type of aerators and limitations. Generally, all these things will be discussed further in literature review section. To simplify the study scope, student is expected to be able to explain the aeration for the whole at the end of the study. The set of questions below will portray the gist of the scope of study:

1. What is the purpose of Aeration and why is it commonly used ?
2. What is the main function of the aeration ?

3. What is the most suitable method for aeration and what is the equipment used for it ?
4. What the significant of variation value of K and R?
5. What are the factors contribute to the different value of K and R in different samples?

CHAPTER 3

LITERATURE REVIEW AND THEORY

3.1 Aeration In General

The general idea behind aeration is to bring the water into intimate contact with the air. Either the water may be discharged into free air or the air may be forced into a body of water. [Gary L.Rogers, 2001]. Apparatus used includes: low cascades, multiple jet fountains throwing water to considerable heights, multitudinous spray nozzles discharging not far above the surface of a reservoir, superimposed trays or shelves, submerged perforated pipes, and porous tubes and plates. Motivation has been by gravity head for water, pumping head for water and pumping head for air.

Chronologically, working installations consisted, first, of cascades and gravity operated multiple-jet fountains, then forced aeration for a few years of commercial exploitation, followed by low-throwing spray nozzles, and finally, diffusion of air through porous tubes and plates in water.

3.2 Purpose Of Aeration

As suggested by B.Marangoly, Term Project 1994, the basic purpose of aeration is for improvement of the physical and chemical characteristics of waters for public supply. Primarily, this improvement involves the reduction of objectional tastes and odors, but some additional benefits of aeration, as a preliminary step to other purification processes have also been noted.

Aeration of such waters improves their taste by supplying the deficient oxygen, rescuing the free carbon dioxide and eliminating much of the hydrogen sulfide and other odorous constituents present. Removal of iron and manganese from such oxygen

deficient waters also usually requires aeration as an initial step. This initial step allows for the lower oxides of these minerals that are dissolved in the water and combined with carbon dioxide to be converted to higher insoluble oxides and in turn removed by subsequent sedimentation, contact or filtration.[Illinois Environmental Protection Agency 1994]

3.3 Definition of aeration

Aeration is necessary to promote the exchange of gases between the water and the atmosphere. In water treatment, aeration is practiced for three purposes: [Patrick Udeh, 2003]

- To add oxygen to water for imparting freshness e.g., water from underground sources devoid of or deficient in oxygen.
- Expulsion of carbon dioxide, hydrogen sulphide and other volatile substances causing taste and odor e.g., water from deeper layers of an impounding reservoir.
- To precipitate impurities like iron and manganese in certain forms e.g., water from some underground sources.

3.4 Types of Aerators

Specifically, there are two types of aerators depending upon the mechanics of aeration. Those forming drops or thin sheets of water exposed to the atmosphere; i.e. water is exposed to come in contact with the ambient air; and those forming small bubbles of air, which rise in the water i.e. air is brought in contact with the water. Spray, waterfall or multiple tray, cascade and mechanical aerators can be considered under one type, while diffusion aerators fall under different type. [Safe Water From Every Tap: Improving Water Service to Small Communities (1996); *Commission on Geosciences, Environment and Resources*]

3.4.1 *Spray Aerators*

When water is sprayed through nozzles upward into the atmosphere it is then broken up into either mists or droplets. Water is directed vertically or at a slight inclination to the vertical. The installation consists of trays and fixed nozzles on a pipe grid with necessary outlet arrangements.

Nozzles usually have diameters varying from 10 to 40 mm spaced in the pipe at intervals of 0.5 to 1 m or more. Special (patented) types of corrosion resistant nozzles and sometimes plain openings in pipes, serving as orifices, are used. The pressure required at the nozzles head is usually 7 m of water but practice varies from 2 to 9 m and the discharge ratings per nozzle vary from 18 to 36 m³/hr. Usually aerator area of 0.03 to 0.09m³/hr of design flow is provided.



Figure 3.1: Spray aerator

3.4.2 *Waterfall or Multiple Tray Aerators*

Water is discharged through a riser pipe and distributed on to a series of trays or steps from which water falls either through small openings to the bottom or over the edges of the trays. Water is caused to fall into a collection basin at the base. In most aerators, coarse media such as coke, stone or ceramic balls, ranging from 50 to 150 mm in diameter are placed in the trays to increase the efficiency.

For iron removal this may be beneficial. The trays about 4 to 9 in number (with a spacing of 300 mm to 750 mm) are arranged in a structure 1 m to 3 m high. With the media, good turbulence is created and large water surface is exposed to the atmosphere. By the addition of more trays, the time of contact can be increased. The space requirements vary from 0.013 to 0.04 m² per m³/ hr of flow. Natural ventilation or forced draft is provided. Removal efficiencies varying from 65 to 90 per cent for CO₂ and 60 to 70 percent for H₂S have been reported.

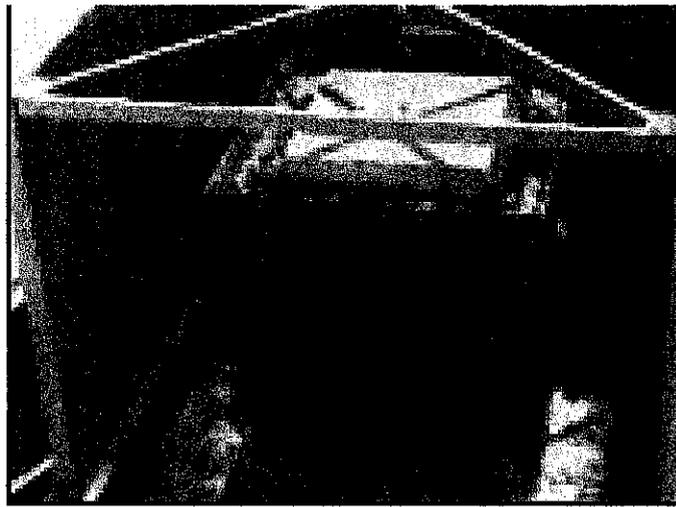


Figure 3.2 : Waterfall or Multiple Tray Aerators

3.4.3 Cascade Aerators

In cascade aerators water is allowed to flow downwards after spreading over inclined surface in thin sheets and the turbulence is secured by allowing the water to pass through a series of steps or baffles. The number of steps is usually 4 to 6. Exposure time can be increased by increasing the number of steps and the area to volume ratio improved by adding baffles to produce turbulence. Head requirements vary from 0.5 to 3.0 meters and the space requirements vary from 0.015 to 0.045 m²/m³/ hr. In cold climates, these aerators must be housed with adequate provision for ventilation. Corrosion and slime

problems may be encountered. The gas transfer efficiency is less compared to the spray type. Removal of gas varies from 20 to 45 percent for CO₂ and up to 35 percent for H₂S.

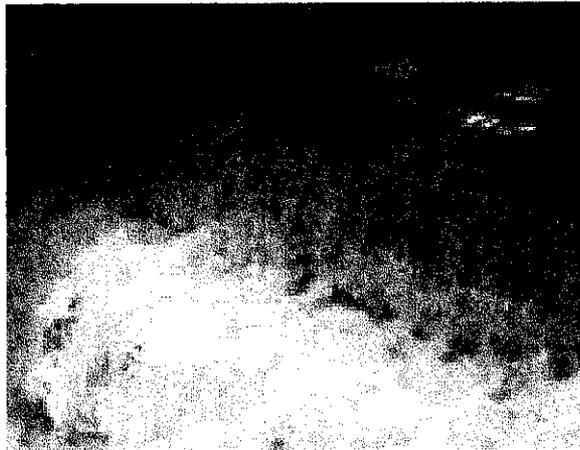


Figure 3.3 : Cascade Aerator

3.4.5 Diffused Air Aerators

This is an obverse of waterfall type aerator. This type of aerator consists of a basin in which perforated pipes, porous tubes or plates are used for release of fine bubbles of compressed air, which then rise through the water being aerated. As the rising bubbles of air have a lower average velocity than the falling drops, a diffused air type provides a longer aeration time than the water fall type for the same power consumed. These have higher initial costs and require greater recurring expenditure. Tanks are commonly 3 to 4.5 m deep and 3 to 9 m wide.

Compressed air is injected through the system to produce fine bubbles, which on rising through the water produce turbulence resulting in a continual change of exposed surface. Ratios of width to depth should not exceed 2:1 for effective mixing and the desired detention period varies from 10 to 30 minutes. The amount of air required ranges from 0.06 to 1m³ of air per m³ of water treated. The air diffusers are located on one side of the tank. The power requirements of blower vary from 3 to 13 w/m³/hr.

The air should be filtered before passing through porous diffusers. Oil trap is also provided before diffusers. Diffused aerators require less space than spray aerators but

more than tray aerators. Cold weather operating problems are not encountered. The aerators can also be used for mixing of chemicals.

3.5 General Theory of aeration

There are several theories proposed for the mechanism of oxygen transfer in water. These theories are widely used in modeling oxygen transfer kinetics. Interestingly, the simpler forms have proven effective in Aeration design yielding results close to more complex models and usually provide equivalent predictions of oxygen transfer. The rate of gas movement into a liquid is described by **Fick's first law**. The relationship describes the rate of mass transfer as directly proportional to the concentration gradient. It's expressed as:

$$\frac{dm}{dt} = \frac{D_m A dC}{dt} \quad (1)$$

In the equation, dm/dt is the mass transfer rate in gram per second (g/sec), D_m is the molecular diffusion constant (or coefficient) of the gas in square centimeters per second (cm^2/sec), A is the area through which transfer occurs (cm^2), and dC/dt is the concentration gradient of the gas.

One of the earliest model for gas transfer suggest 2 laminar films of gas and liquid exist at the interface of two phases. The model is referred to as the "two film model", or Lewis and Whiteman model after its original presenters. Gas move through the liquid film by molecular diffusion and is distributed in the liquid by turbulent diffusion. The two film model for oxygen transfer describe the rate of transfer by the following:

$$\frac{1}{A} \frac{dm}{dt} = \frac{D_m (C_s - C)}{L_f} \quad (2)$$

In this equation, $\frac{1}{A} \frac{dm}{dt}$ is the rate transfer per unit area, C_s is the saturation concentration of gas, L_f is the thickness of liquid film, and C is the gas concentration. The model is based on stable laminar film at the interface requiring tranquil flow conditions. These conditions are rarely found in the field, yet Equation 2 has been employed widely to effectively describe oxygen transfer and aeration design for many applications. The basic model for oxygen transfer used for sizing aeration system is based on the Lewis and Whitman model. The following equations present the model in differential form and exponential form:

$$\frac{dC}{dt} = K_{La}(C_s - C) \quad (3)$$

$$C = C_s - (C_s - C_0)\exp(-K_{La} \times t) \quad (4)$$

In these equations, C is the dissolved oxygen (DO) concentration in milligram per liter (mg/L), C_s , is the equilibrium concentration of DO attained as time approaches infinity, C_0 is the DO concentration at time zero, and K_{La} is the mass transfer of re-aeration coefficient (hr^{-1}) defined as the rate of mass transfer per unit volume divided by the concentration differential gradient ($C_s - C_0$), and t is time (hr).

3.6 Theory Applied to Achieve Coefficient absorption K and the Oxygenation Capacity of a system R

In this project, the type of aeration used is air diffusing aeration. The theory used in the experiment is slightly different and more specific in order to find the value of absorption coefficient, K and oxygenation capacity, R . A gas forming part of an atmosphere in contact with a liquid in which it is soluble will pass into solution up to the point at which the concentration of the gas in the liquid is in equilibrium with the concentration of the gas in

the atmosphere. This equilibrium point is determined by the coefficient of absorption K_s , which is the value of the concentration of the gas in the liquid when the atmosphere is composed entirely of the gas under consideration.

It can be showed that :

$$K = \frac{(\ln D_1 - \ln D_2)}{t_2 - t_1} = \frac{(2.303 \log D_1 - \log D_2)}{t_2 - t_1} \quad (5)$$

Where D_1 and D_2 are selected readings of oxygen concentration in mg/l and t_2 and t_1 are corresponding values of time. The oxygenation capacity of a system is defined as the rate of absorption of oxygen during the aeration of completely de-oxygenated water at 10°C. It is shown as :

$$R_{(10)} = \frac{KFC_{s(10)}V\text{grams}}{\text{hours}} \quad (6)$$

Where F is a temperature correction factor and C is the saturation concentration, V is volume of water. (Correction factor table can be referred in *appendices* Table 10)

3.7 Description of Diffused air system

The waste water treatment industry has witnessed the introduction of wide variety of air diffusion equipment. In the past, the various devices have commonly classified as either “fine bubble” or “coarse bubble”, a designation that supposedly reflected the device’s efficiency in transferring oxygen. Unfortunately, the fine bubble diffused aeration is difficult to define and the demarcation between fine and coarse bubbles is not well differentiated. Also, there has been considerable debate and confusion over which classification applied to certain equipment. For these reason, the current industry preference is to categorize diffused aeration system by the physical characteristic of the equipment. There are 2 major diffuser systems:

- Porous diffuser
- Non porous diffuser

Porous Diffuser system. Use of porous diffuser has gained renewed popularity because of the relative high oxygen transfer efficiency exhibit by most of these systems. There are many types of material used as a media of the system such as ceramic materials, plastic materials and flexible sheaths. Porous diffuser also come In different form of shape. Porous diffusers are available in plates, domes, disc, and tubes diffusers.

Non porous Diffuser. Non porous diffusers differ from porous devices because they use larger orifices or openings that do not easily clog. Non porous diffusers are available in a wide variety of shapes and materials. Non porous diffuser familiar with fixed orifice diffusers, valve orifice diffusers, static tube and serrated hose.

Diffuser Used in Experiment : Sparger tube

In the aeration study, the diffuser used for the whole disciplines (except to compare effect of different diffuser arrangement) is *sparger*. Sparger is one type of fixed orifice diffuser which is under non porous diffuser category. This sparger is a standard type of diffuser used in many kind of 'Pilot Aeration' studies which normally used in any University Laboratory. Spargers were introduced in 1954 to provide nonclog performance with transfer efficiencies greater than perforated pipes. The devices typically constructed of molded plastic and are saddled mounted below the air header at a center-to-center 0.3 to 0.6 cm. The blowoff leg purge liquid and relieve air at high flow rates or when the orifices on the sparger plug. When plugging occurs, the air flows exits from the drop pipe and poorer oxygen transfer results. It is difficult to tell from the tank surface appearance that anything has happened. A drop in DO or increased air supply could be indicating factors.

3.8 Fine and Coarse Bubbles Diffuser System

3.8.1 *Fine Bubbles diffuser system*

Fine bubble aeration is a subsurface form of diffusion in which air is introduced in the form of very small bubbles to aid or enhance the treatment of wastewater. Air flows from a pipe into diffusers located at the bottom of a tank. These diffusers have numerous small openings (known as pores) through which air flows into the wastewater in the tank.

In a fine bubble aeration system, several diffusers are mounted or screwed into a header pipe that may run along the length or width of the tank or on a short manifold mounted on a movable pipe. These diffusers come in various shapes and sizes, such as discs, tubes, domes, and plates. Fine pore diffusers (discs, tubes, domes, and plates) are usually made from ceramic, plastic, or flexible perforated membranes. Although many materials can be used to make fine pore diffusers, only these few are being used due to cost considerations, specific characteristics, market size, and other factor.

3.8.2 *Advantages of Fine Bubbles*

- Exhibit high OTEs
- Exhibit high aeration efficiencies (mass oxygen transferred per unit power per unit time)
- Can satisfy high oxygen demands
- Are easily adaptable to existing basins for plant upgrades
- Result in lower volatile organic compound emissions than nonporous diffusers or mechanical aeration devices

3.8.3 *Coarse Bubbles diffuser system*

In the past, various diffusion devices have been classified as either fine bubble or coarse bubble based on how efficiently they transferred oxygen to the wastewater. Since it is difficult to clearly distinguish between fine and coarse bubbles,

diffused aeration systems have been classified based on the physical characteristics of the equipment. The common types of coarse bubble diffusers are fixed orifices, valve orifices, and static tubes. The bubble size of these diffusers is larger than the porous diffusers, thus, lowering the oxygen transfer efficiency (OTE).

3.8.4 Advantages of Coarse Bubbles

- Coarse bubbles diffusers are not susceptible to chemical or biological fouling, so that may not impair transfer efficiency and generate low headloss; as a result they are not require routine cleaning.
- Coarse bubbles diffusers may not be susceptible to chemical attack (especially perforated membranes); therefore, simple care is enough in selection of materials for a given wastewater.
- Because of the low efficiencies of coarse bubbles diffusers at low airflow rates, airflow distribution is not critical to their performance and selection of proper airflow control orifices is not become important.
- Because of the low efficiencies of coarse bubbles diffusers, required airflow in an aeration basin (normally at the effluent end) may not be dictated by mixing-not oxygen transfer.

3.8.5 Coarse and Fine Bubbles Distribution

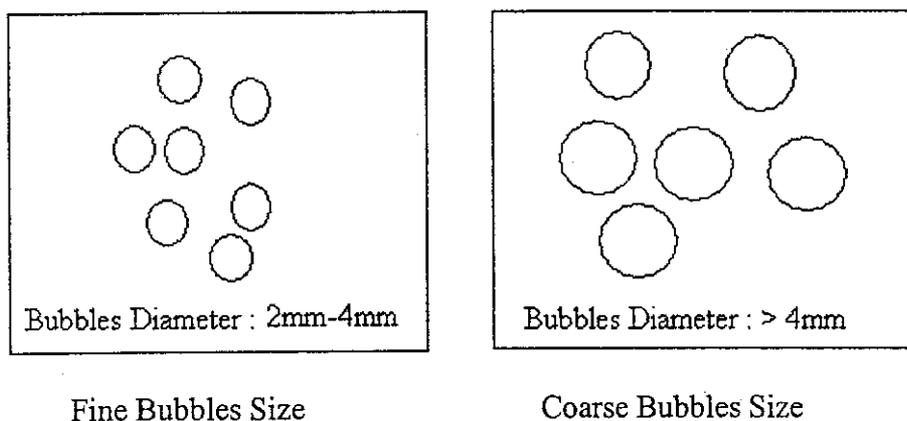


Figure 3.4 : Fine Bubbles and Coarse Bubbles Identification

CHAPTER 4

METHODOLOGY / PROJECT WORK

4.1 Equipment/Tools Required for This Project

No	Equipment	Frequency of Use (hours per week)
1	Aeration Unit	15 hours
2	DO meter	15 hours

Chemicals of Other Materials Required for This Project

No	Chemicals/Materials	Quantity (Volume, mass etc)
1	Water samples; lakes, rivers	20 L per experiment
2	Sodium Sulphite solutions	2-3 liters
3	Cobaltus Chloride	2-3 liters

4.2 Description of the Unit

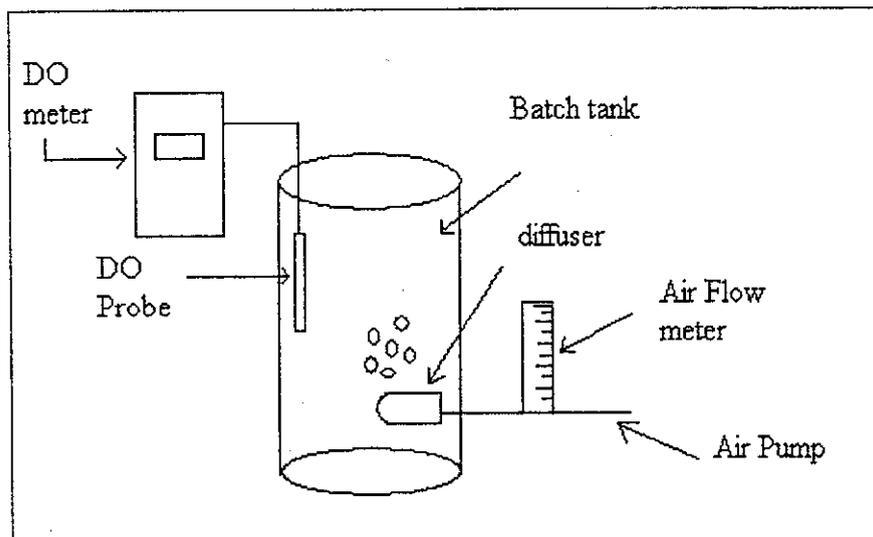


Figure 4.0 : Sketch for Experiment Set Up

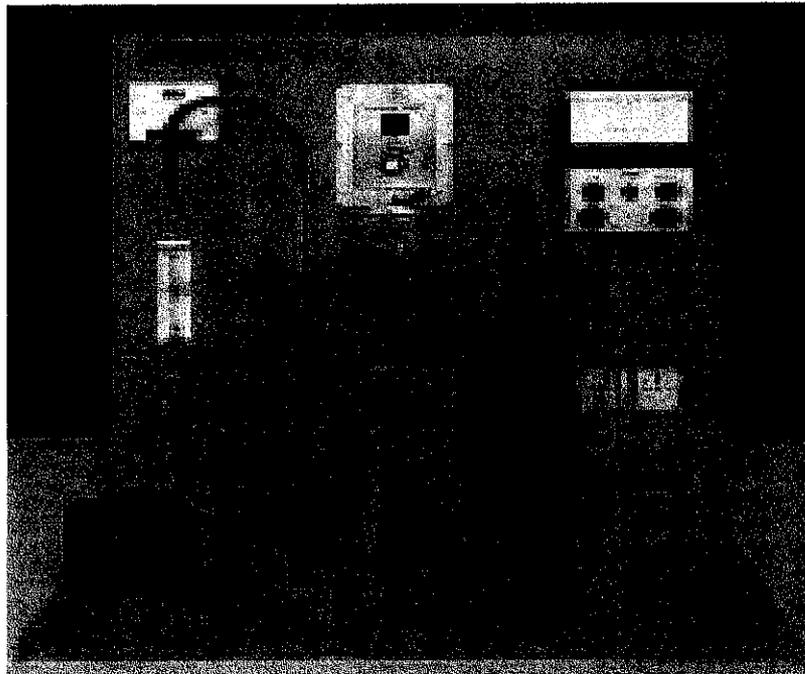


Figure 4.1 Armfield Aeration Unit

The purpose of the Armfield Aeration Unit is to permit study of the oxygen transfer characteristics of diffused air systems and the physical and chemical parameters which influence their oxygenation capacity. These studies are a necessary prelude to the understanding of the biological treatment of waste waters. The Armfield Aeration Unit comprises an open tank equipped with a paddle stirrer. Air is supplied by an eclectically driven pump through a control valve and flow meter to a diffuser, adjustable for position, within the tank. A variety of diffusers is included. The dissolved oxygen content of the water in the tank is measured by means of an oxygen electrode and dissolved oxygen meter. The meter supplied gives an additional direct reading of water temperature. Operating from internal batteries, the meter may be used for field trials independently of the apparatus.

The equipment consists of a base and backboard standing on four rubber feet. Mounted on the base is the clear acrylic water tank which has a capacity of 24.5 liters. On the front of the tank is a depth gauge and at the base a drainage tap. The lid of the tank is partially removable to allow filling. On the fixed part of the lid are mounted the stirrer motor, stirrer and clamping positions for the temperature probe, oxygen probe and aerator tube.

The oxygen/temperature meter is mounted on the backboard with the connecting leads to the appropriate probes. Air is supplied to the tank by means of a pump (with filter and silencer assembly) and is controlled by a valve flow meter discharging through the aerator tube. Three diffusers, sparger tube, treble air stone and single air stone, may be separately attached to the aerator tube. Variable speed adjustment of the stirrer paddle provides different levels of turbulence in the tank

Demonstration Capabilities

- effects of oxygen transfer under non-steady state conditions
- measurement of the absorption coefficient K and the oxygenation capacity R
- the effect on K and R of:
 - degree of fluid mixing,
 - water temperature,
 - gas flow rate,
 - depth of water,
 - diffuser arrangement,
 - water composition.

4.3 Procedure Identification/Experiment Procedures

4.3.1 Experiment 1: To study Oxygen transfer under non-steady state condition

1. The following solutions is prepared:

- 10% solution of sodium sulphite, Na_2SO_3 . 10g of the salt is dissolved in distilled water and make up to 1 liter.
- 1% solution of cobaltus chloride, $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$. 10g of the salt is dissolved in distilled water and make up to 1 liter. This acts as a catalyst to the reaction between the sodium sulphite and oxygen.

2. Vessel is filled with tap water, or other samples to be investigated to the required level. A quantity of 20 liters is used, but this may vary for comparative
3. The diffuser and oxygen electrode is located at the desired positions. (See note under item 6 below)
4. The stirrer is run at moderate speed and 1.5 ml of the sodium sulphite solution per liter water in the vessel is added, 0.5ml of the cobalt chloride solution per liter water is also added. These quantities should be sufficient to de-oxygenate the water. The dissolved oxygen level is measured to ensure that it is less than 10% of the saturation value, and if necessary, a little more of each solution is added to bring the level to near zero.
5. The air-flow is started and adjusted to the desired value; e.g 5 liters per minute.
6. The stirrer is run at the lowest speed at which the contents of the vessel are adequately stirred.

Note : It is important to ensure that the diffuser and oxygen electrode are so located that air bubbles are not carried into contact with the electrode. This would lead to false oxygen readings.

7. Oxygen reading is taken at intervals of 2 minutes once the air flow has been established at required steady rate. The reading is taken until oxygen level reaches saturation. It will consume 10 to 30 minutes depending on the conditions of the experiment.
8. Temperature readings in the water is taken at each reading of oxygen concentration in the course of experiment. Average temperature reading is used in subsequent calculations.

4.3.2 Experiment 2: To study the effects of different air flow rates on the K value and R value.

1. The same procedures as in Experiment 1 (step 1-8).
2. experiment is repeated using different flow rates .
 - 8 l/min
 - 12 l/min

4.3.3 Experiment 3 : To study the effect of different designs of diffusers on K value and R value

1. The same procedures as in Experiment 1 (step 1-8).
2. Experiment is repeated using different type of diffuser.
 - Sparger tube
 - single airstone

4.3.4 Experiment 4 : To study the effect of water depth on the K value and R value

1. The same procedures as in Experiment 1 (step 1-8).
2. Experiment is repeated using different level of water depth.
 - 100mm
 - 200mm
 - 300mm

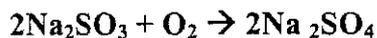
4.3.5 Experiment 5 : To study the effect of different type of waste materials on K value and R value

1. The same procedures as in Experiment 1 (step 1-8).
2. Experiment is repeated using different water samples.
 - lake A (Behind UTP mosque)
 - lake B (Beside Ruby Block)

4.4 Summary of Test Methods

4.4.1 Absorption Measurements

The oxygen transfer is determined from the increase previously, artificially lowered DO concentration. The depletion of oxygen can be implemented by either adding chemicals or stripping with nitrogen gas. Normally, sodium sulphite is used to decrease the oxygen by the reaction :



To remove 1 kg of dissolved oxygen 8 kg of Na_2SO_3 is required. In order to expedite the reaction, the catalyst of cobalt should be introduced into a test tank. After the DO reach zero, the aeration system will be switched on. By dissolving the oxygen of the air into the water, the oxygen concentration increase according to the saturation function:

$$C_t = C_s - (C_s - C_0) \cdot \exp(-K_{l,a} t^*)$$

Where C_t , C_s and C_0 is the DO concentration at time t , saturation point and initial point respectively. $K_{l,a}$ can be obtained by the relationship between C_t and t .

4.4.2 Adding Chemicals (Absorption Measurements)

All the chemicals should be dissolved before they are added. The amount of sodium sulphite should be 10%-15% more than calculated result due to a lag time for admixture. Normally a cobalt concentration in water of 0.5 mg/L is sufficient. If the test water is kept

the same, one time of addition of cobalt is enough. Cobalt should be added before sodium sulphite.

4.4.3 Temperature Measurement

The temperature of test water can be read from the DO meter. The variation of temperature shall be with an accuracy of ± 0.5 °C at the beginning and the end of each test.

4.4.4 Air Flow Rate Measurement

A laboratory flow meter is used to measure the airflow rate. The accuracy of the flow meter has been checked before application. The inverse measuring cylinder filled with water was used to calibrate airflow rate. The airflow of 4 l/min, 8 l/min and 12 l/min are used in the measurement.

Oxygen Probe

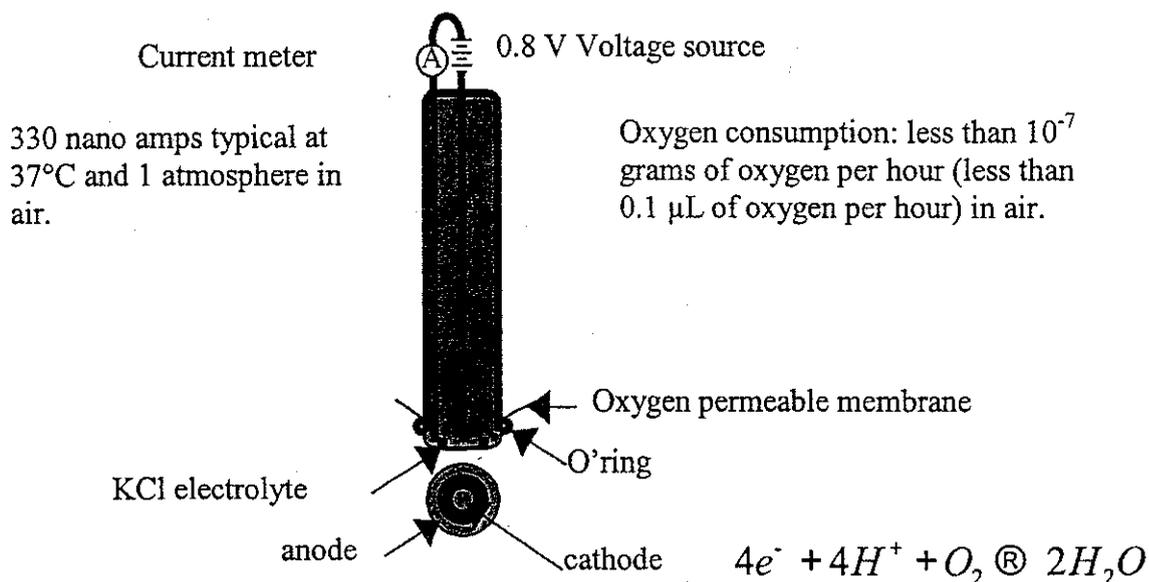
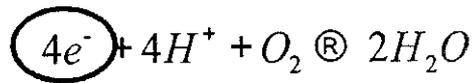


Figure 4.2 : Oxygen Probe diagram

4.4.5 Dissolved Oxygen Probe: Theory



- Applied 0.8 V reduces O_2 to H_2O at the cathode and keeps the O_2 concentration very low
- The cell is separated from solution by a gas permeable membrane that allows O_2 to pass through.
- The rate at which oxygen diffuses through the gas permeable membrane is proportional to the difference in oxygen concentration across the membrane (proportional to the oxygen concentration in the solution)
- Oxygen reduction produces a current that is measured by the meter

CHAPTER 5

RESULT AND DISCUSSION

5.1 Findings and Discussion

There are 15 set of experiment has been done using aeration unit w10 located at chemical lab building 05. They covered the objective 1,2, 3, 4 and the unsteady state condition which is the main objective. Those 15 set of testing covered Lake A and lake B. Below are the graph, calculation and discussion indicate the finding of K and R value for the whole 15 experiment.

5.1.1 Significant Value for Unsteady State Condition of Lake A and Lake B

Findings for comparison value of Unsteady state for Lake A and lake B are shown in figure5.1

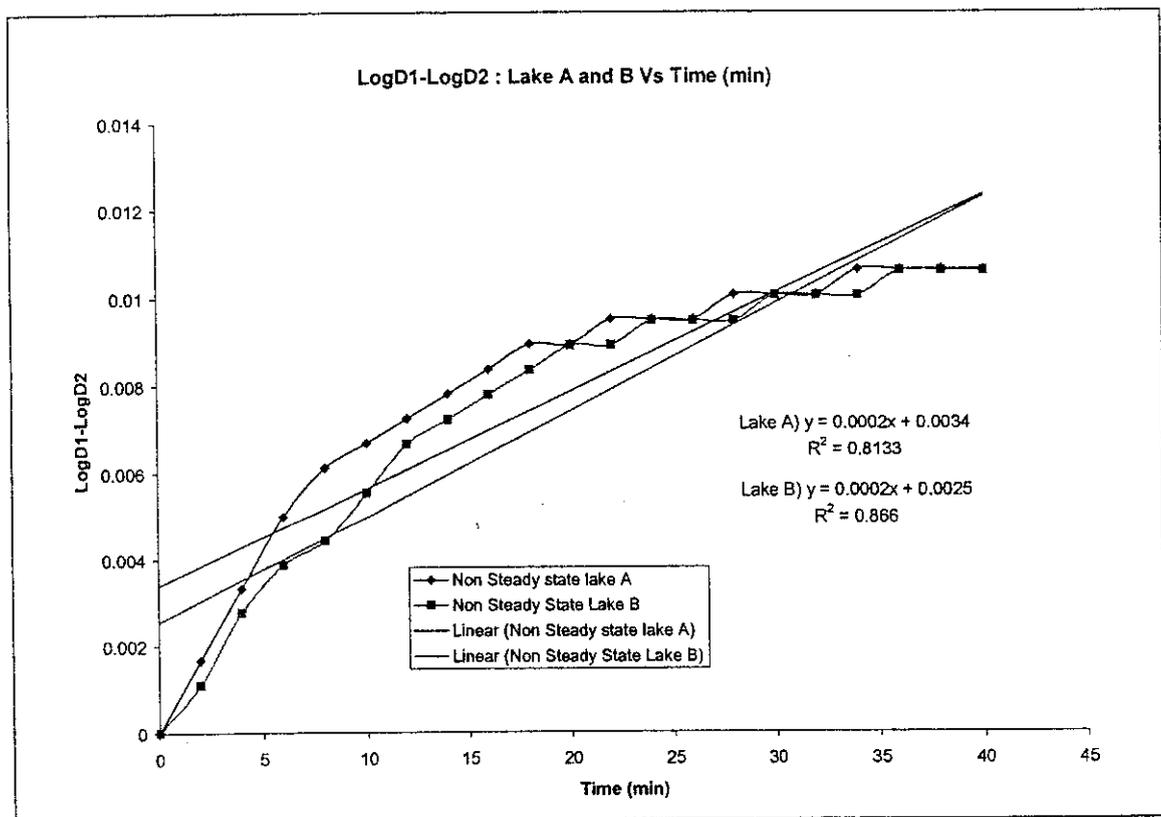


Figure 5.1 : Unsteady State Condition for Lake A and B

The experiment is to study the transfer coefficient K and oxygenation capacity R under non steady state condition for Lake A and Lake B. The experiment is done under non steady state since the temperature is not constant. Standard airflow rate used is 4 l/min and mixer speed is set to be 200 rpm. The temperature drops as the time goes by during the experiment. From the figure 5.1, it is showed that the slope for both lake data is the same, 0.0002, which give K value 0.0004606 mg/L·min. The K value is same because the dissolve oxygen gives significant constant increment from the beginning. It's clear that from the graph trend, dissolve oxygen of lake A is higher than lake B, but the trend of incremental value for both lakes is similar as shown in table 1.0 and 2.0 in the appendices. The different of incremental dissolve oxygen reading is depending on sample material used. To study why the different exist, the biological oxygen demand (BOD) test has been conducted. This type of testing is important because the dissolve oxygen in certain sample is dominated by microbiological or chemicals which consume oxygen. Below are the BOD testing result for both lakes:

BOD Test Lake A	BOD Reading	BOD Test Lake B	BOD Reading
Before test	6.96 mg/l	Before test	6.86 mg/l
After test	5.3 mg/l	After test	4.93 mg/l

Table 5.0 : BOD Testing Result For Lake A and Lake B

Lake A shows higher BOD before and after aeration test compared to lake B. The significant of the BOD result indicates that biological oxygen demand in lake A is less than lake B, which means, the oxygen is much more easier to dissolve in the water for lake A. In other words, the oxygen dissolve, or easily can be stated as oxygen transfer efficiency in lake B is lower due to oxygen consuming by microbes, so lower oxygen solubility. From the BOD test, the result obviously tells why there is different in dissolve oxygen capacity for both lakes even though the incremental trending is similar.

For oxygenation capacity, or simply called oxygen uptake R , the value for both lake is different. Ideally , oxygen uptake rate measurement should be taken immediately at the point of sample collection. But experience shows that accurate measurement of rapid

oxygen uptake is virtually impossible. From the calculation showed in appendices, R value for lake A is 0.003036g/hr while for lake B is 0.003052g/hr. The R value is highly depending on saturation concentration C_s and temperature correction factor F. Table 1.0 and 2.0 shows different average temperature which lead to different saturation concentration and different temperature correction factor. In calculating the R value, both saturation concentration and temperature correction factor are the main concern. The standard tabulated value is given in table 10 but to certain extent, for which average temperature stay in between the value given, the interpolation is necessary to find the exact value of C_s and F. The higher the average temperature, the lower the saturation concentration and temperature correction factor. Indirectly, the lower the average temperature will result lower oxygenation capacity R. From table 1.0 and 2.0, since the average temperature for lake A is higher than lake B, the oxygenation capacity R is lower in lake A compared to lake B.

5.1.2 The Effect of Airflow Rate on the Coefficient K and the Oxygenation Capacity R for Both Lakes.

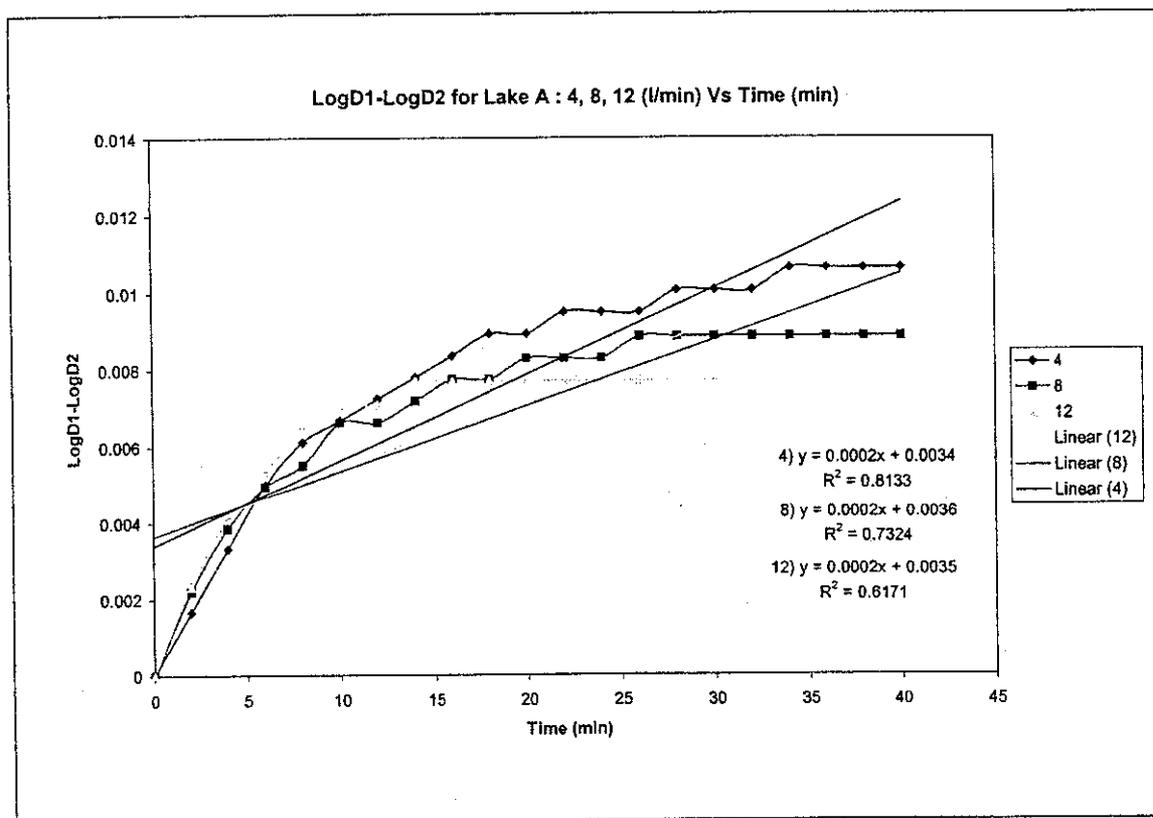


Figure 5.2 : Different Airflow Rate for Lake A

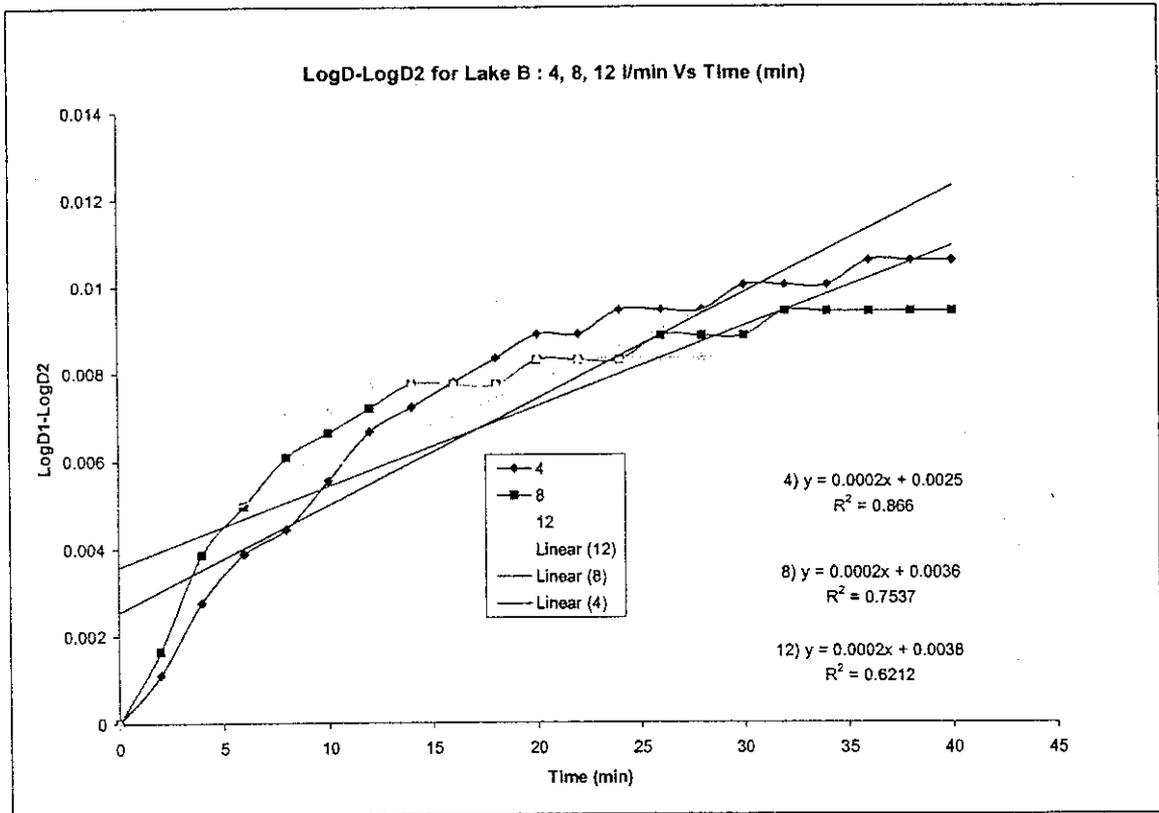


Figure 5.3: different Airflow rate for Lake B

Figure 5.2 and 5.3 shows the dissolve oxygen trend when the airflow varies. Three set of airflow rates has been applied in the experiment for both lakes. 4 l/min, 8 l/min, and 12 l/min of airflow rate are selected to indicate the low, medium and high airflow through the diffuser. For both lakes, the trend of dissolve oxygen is similar at the early phases. 12 l/min of airflow rates shows the highest oxygen dissolve followed by 8 l/min and 4 l/min. For lake A, the dissolve oxygen capacity can be checked by comparing the data from table 1.1, 1.2 and 1.3. One parameter is choose, for example, the dissolve oxygen reading at 10th minutes. At 4 l/min, 8 l/min and 12 l/min, the dissolve oxygen rate is 0.13 mg/l, 0.17 mg/l and 0.18 mg/l. Same goes to the lake B, the dissolve oxygen capacity can be checked by comparing the data from table 2.1, 2.2 and 2.3. At 10th minutes, the dissolve oxygen reading for 4 l/min, 8 l/min and 12 l/min are 0.11 mg/l, 0.16 mg/l and 0.17 mg/l.

The different reading is depend on amount of oxygen in form of bubbles which delivered into the sample. Since the diffuser used is non porous diffuser, so the bubbles produced is considered coarse pore bubbles. The diameter of coarse pore bubbles is larger than 2 mm. Surface bubbles area play important role to measure how much oxygen can be delivered into the samples. In this case, the higher the airflow rate, the more bubbles produced, so the larger the surface area will enable the oxygen to dissolve faster. Since the oxygen transfer is closely related to surface area contact between air and the water, the smaller the bubbles will result better transfer.

By the way, in this experiment, K value does not affected by varying the airflow rate for both lake samples. It is found that the transfer coefficient K is constant. The constant K value is influenced by the coefficient of equipment efficiency. Some factors can support the result. The experiment conducted is not full scale experiment. So the effectiveness of the result is arguable. Furthermore, the diffuser used is the same for all the different airflow which is sparger tube diffuser. So, it produced the same bubbles diameter. Even though the amount of bubbles is increasing proportionally to airflow rate incremental, but it has not giving any significant effect on transfer coefficient K. It is also found that varying the airflow rate does not make sense in incremental trending of dissolve oxygen for both lakes.

As for oxygenation capacity R, the value is different for different airflow rate. But the differences is not actually depend on airflow rate, but most likely it concern with average temperature, saturation concentration and temperature correction factor. [Martin R. Wagner and H. Johannes Pöpe].

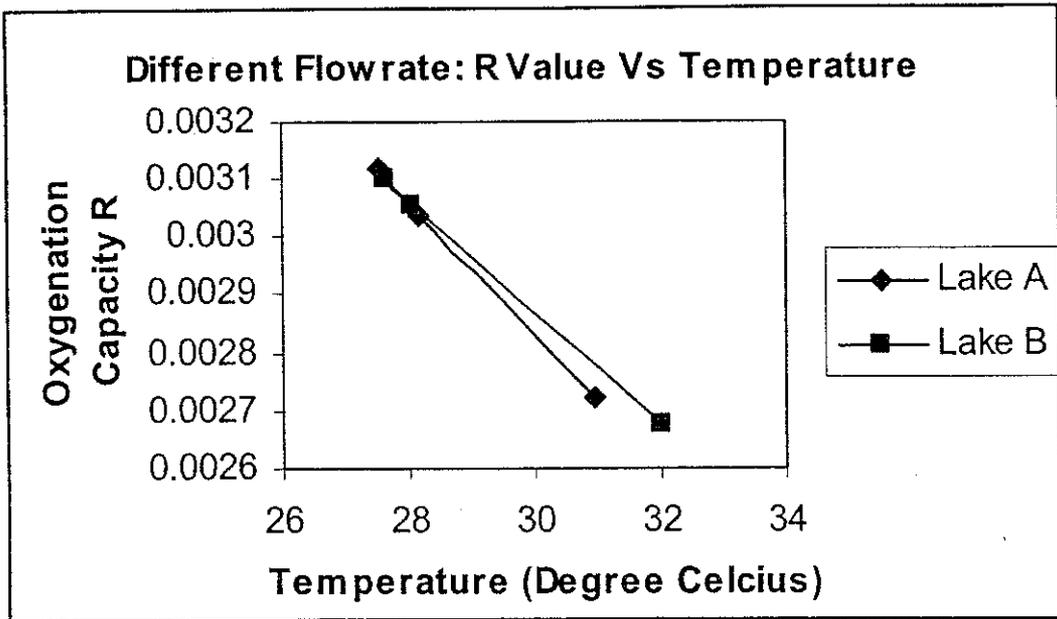
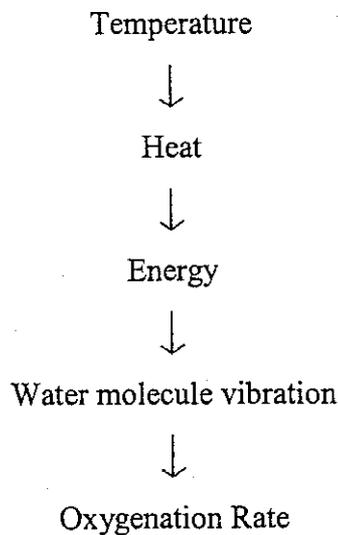


Figure 5.4: Significant of R Value with Temperature

From figure 5.4, it shows that the R value decrease as temperature increase for both lakes. The average temperature difference is depend on weather and what period the experiment is conducted. The R value represents the oxygenation capacity in water samples. Theoretically, the oxygenation rate is higher in cold weather (low temperature) and vice versa. The relationship of heat and energy can explain the phenomenon,



As the temperature increase, the heat is increased, so more energy is produced. Water molecule vibration will also increase because it received high energy due to temperature rising. Oxygen which supplied by diffuser pores is in gases form. The oxygen gases facing difficulties to oxygenate in high water molecule vibration because the spaces and retention time required by oxygen to oxygenate is uncertain due to rapid water molecule movement. [Connie D. DeMoyera, Erica L. Schierholza and John S. Gulliver, Journal: *Impact of bubble and free surface oxygen transfer on diffused aeration systems*, 2000].

5.1.2 The Effect of Water Depth on the Coefficient K and the Oxygenation Capacity R for Both Lakes.

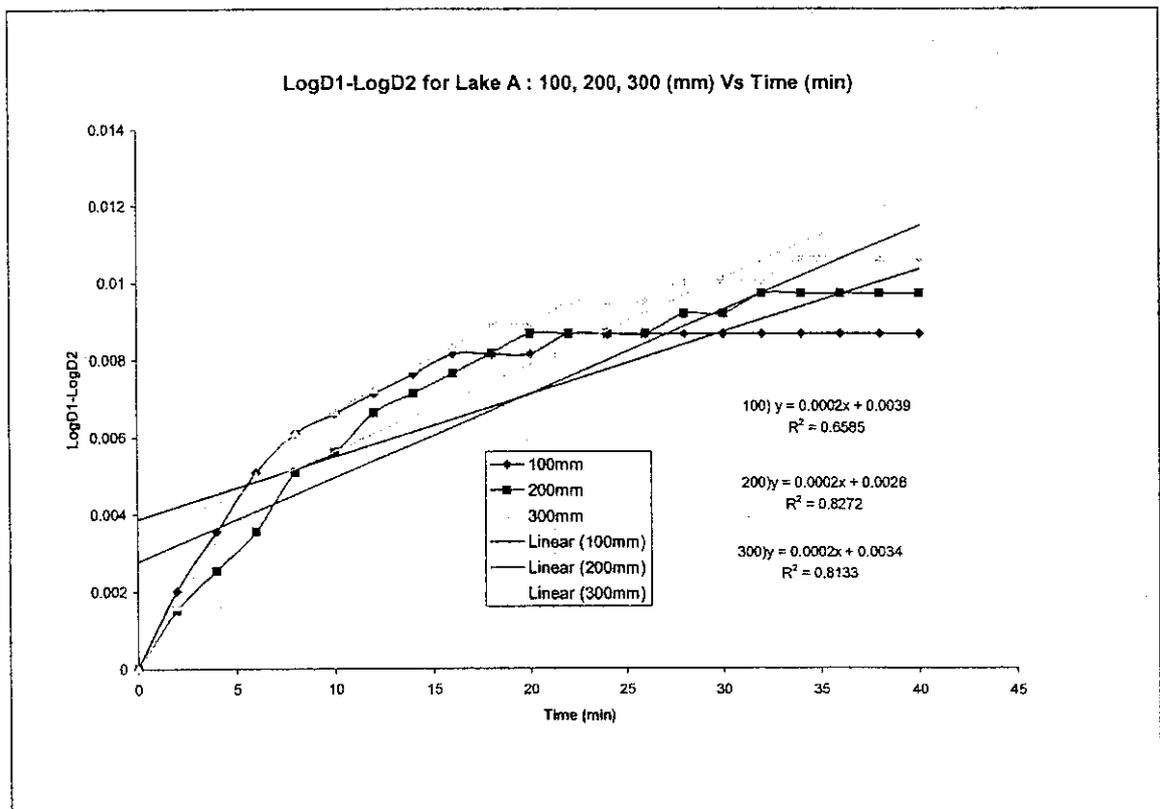


Figure 5.5: Different water Depth of Lake A

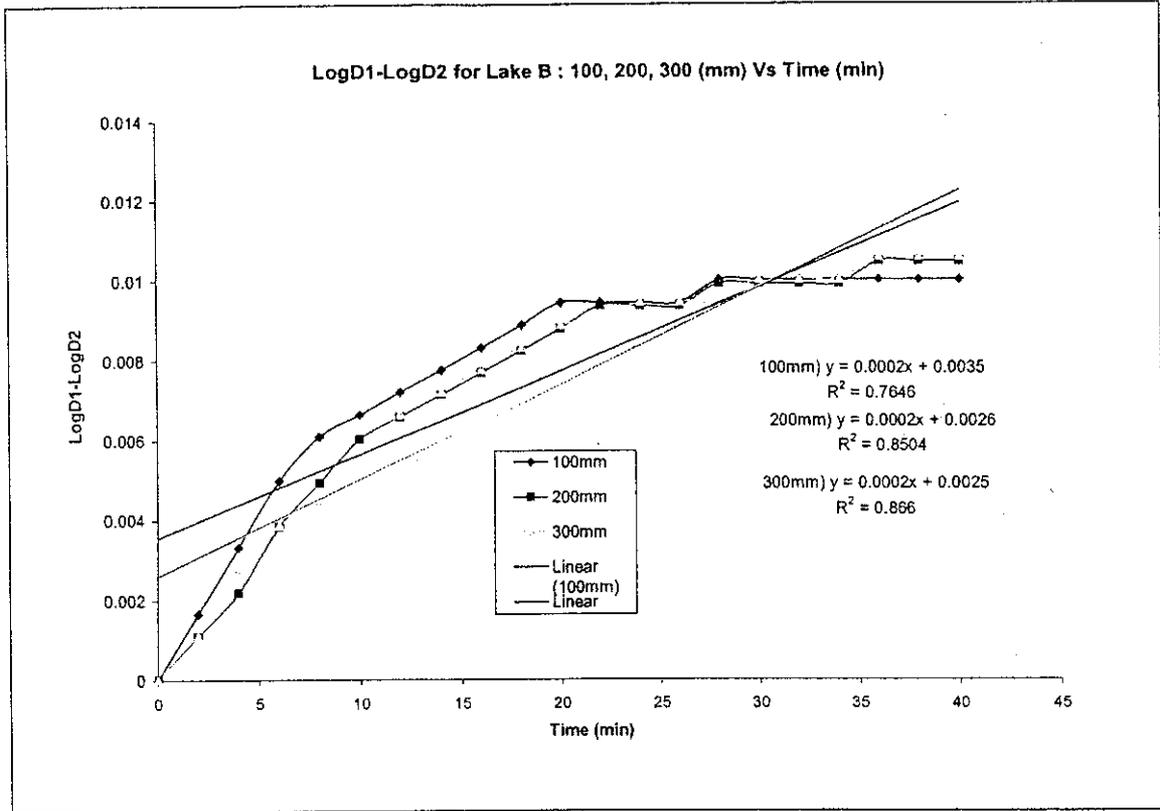


Figure 5.6: Different water Depth of Lake B

Figure 5.4 and 5.5 show the dissolve oxygen trend when the water depth in aeration tank is varies. Three set of water depth has been chose which 100 mm, 200 mm and 300 mm is. The airflow rate is set to be 4 l/min and mixer speed is constant to 200 rpm for each set of water depth. The graph trending of lake A and Lake B for effect study of different water depth in aeration tank is quite similar to the second objective which is the effect study of different airflow rate. The K value is still give constant reading as the dissolve oxygen incremental for the whole set of different depth experiment is the same because diffuser and equipment used does not changed.

Theoretically, the different water depth experiment in aeration tank is to study the effect of bubbles contacting time with water. [AERATION Principles, 2002]. Bubbles contacting time with water is important parameter in aeration study because contacting time usually influences the

aeration effectiveness. The higher the depth, means the more contacting time available for the bubbles to transfer the oxygen into the water. In other words, deeper water will result better aeration performance due to longer time contact between bubbles and the water. [Danley W, 1984]. By the way, in this study, it is found that by using the w10 aeration equipment, the contacting time between bubbles and water does not really matter due to several factors. For lake A, from table 1.4, 1.5 and 1.6, it shows that dissolve oxygen give most rapid increment in 100mm depth, followed by 200mm depth and 300mm depth. Same goes to lake B in table 2.4, 2.5 and 2.6.

The foremost factor leading to this result is diffuser and oxygen probe positioning. The lesser the water depth, the deeper the oxygen probe going inside the tank as it has to reach $\frac{3}{4}$ oxygen probe to be submerged under water. Since the diffuser is located at almost bottom of the tank, the oxygen probe rapidly detect the dissolve oxygen supplied by bubbles from diffuser. Even though the contacting time between bubbles and water is less, but the significant amount of bubbles produced in one time is enough to transfer the oxygen and detected by oxygen probe.

Another factor contributing to this result is constant airflow rate and turbulence flow in the tank. By using constant airflow rate, the bubbles produced in one time are the same in all different water depth. [Martin Wagner, *AERATION Manual Report* 1988].

Different water depth indicates different volume of water in the tank. Theoretically, by using constant airflow rate, it is faster to aerate small volume sample rather than the bigger one. In addition, the lower the water depth, the higher the turbulence flow, so the easier the air water contact and mixing process.

5.1.3 The Effect of Different Type of Waste Material on K value and R value

As stated in the non steady state discussion, the comparison between lake A and lake B is quite similar to explain the waste material effect on K value and R value. But, since the K value for both lake is the same, clean water experiment has been introduced as the control experiment for this objective. Since the explanation of clean water is still not clearly defined, so the clean water experiment has been conducted using tap water. the overall transfer coefficient, K, is a characteristic of a particular system, it would be expected to change with changes in physical or chemical properties of the solution gas is being transferred. Change in gas transfer rate due to changes in physical and chemical properties may be described by the introduction of α . The α coefficient is defined as the ratio of the K value for wastewater to value of the K for clean water:

$$\alpha = \frac{\text{K wastewater}}{\text{K clean water}} \quad \text{----- (Equation 5.0)}$$

Theoretically, the coefficient may be less than or greater than one (should be less than 1), [Paulson, 1976], but should change during treatment and approach unity for treated wastewater, since the substances affecting the transfer rate are being removed.

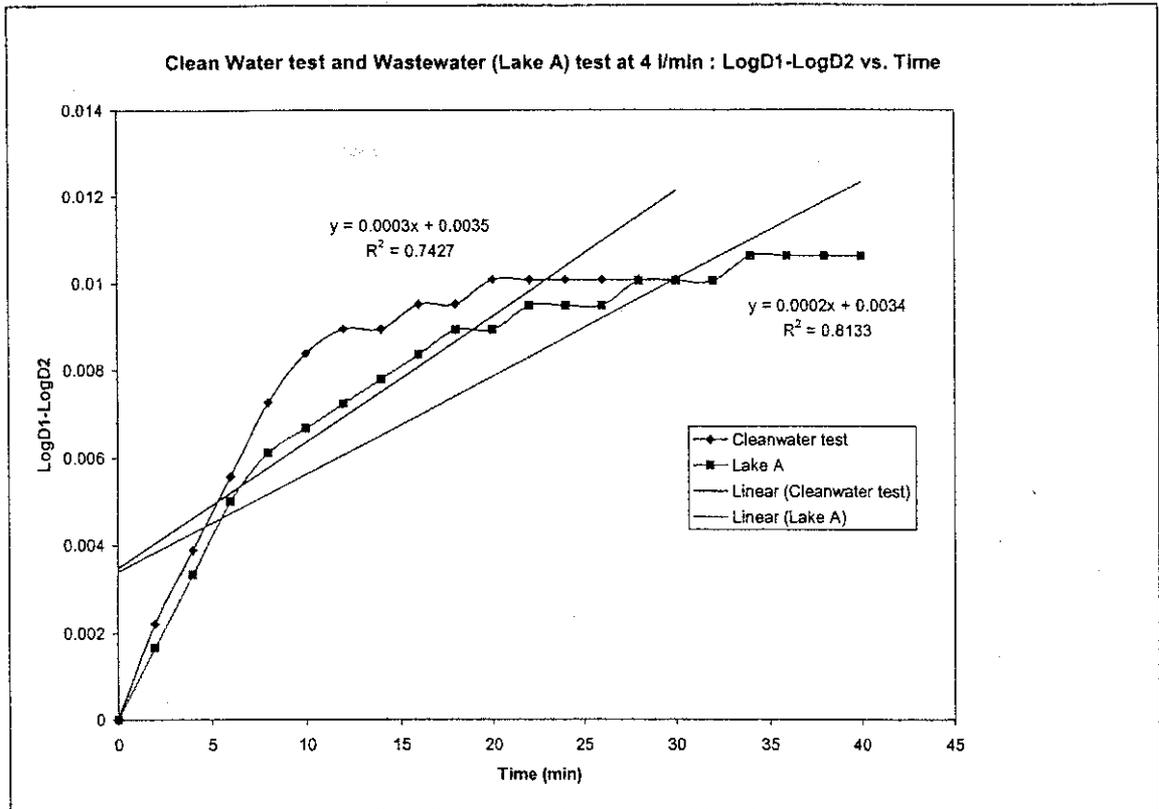


Figure 5.7 : Comparison on Slope value Between wastewater (lake A) and Clean water

From figure 5.7, slope for Clearwater and Lake A give different value. From calculation 8 and 9 in the appendices, the K value for Clearwater and lake A is 0.0004606 mg/L·min and 0.0006909 mg/L·min respectively. The K value is proportionally to R value if any other variables such as average temperature, sample volume and airflow rate is stay the same. [Martin Wagner, *AERATION Manual Report* 1988].

The R value for lake A is 0.003036 g/hr while for Clearwater is 0.004555 g/hr. It is obvious that oxygenation capacity in Clearwater is greater than wastewater lake A. The different of K value and R value is influenced by the rate of dissolve oxygen ability in the sample. As in lake A, the early rate of dissolve oxygen is slower than Clearwater. From table 3.0 and 1.0, Clearwater experiment reach constant value of dissolved oxygen by the time of 20th minutes while lake A experiment only reach constant value of dissolve oxygen by the time of 34th minutes.

The waste material used give significant effect on K value because it is effected by different capacity of dissolve oxygen rate. To verify the acceptability of transfer coefficient, K value for both Clearwater and wastewater (lake A), the calculation of ratio of the K value for wastewater to value of the K for clean water, a from equation 5.0 is performed. [Paulson, "*Oxygen Absorption Efficiency Study*", 1976].

$$a = \frac{K \text{ wastewater}}{K \text{ cleanwater}} = \frac{0.0004606 \text{ mg/L}\cdot\text{min}}{0.0006909 \text{ mg/L}\cdot\text{min}} = 0.6667$$

The α value satisfy the theory which is less than 1.

5.1.4 The Effect of Different Diffuser Arrangement on K and R values.

The last objective is to study the effect different diffuser arrangement on K value and R value. Default diffuser which is used in this experiment is sparger tube. Sparger tube is considered as non porous aerator and it produces coarse bubble.[Danley W, 1984]. Since sparger tube produces coarse bubble, so it is grouped under non porous diffuser. To compare the diffuser effect on K value and R value, another type of diffuser is used. To differentiate the diffuser efficiency, single air stone diffuser has been chose because it provides fine bubbles.[Toerber and Mandt 1979]. Below are the raft shape and working principle for both diffuser.

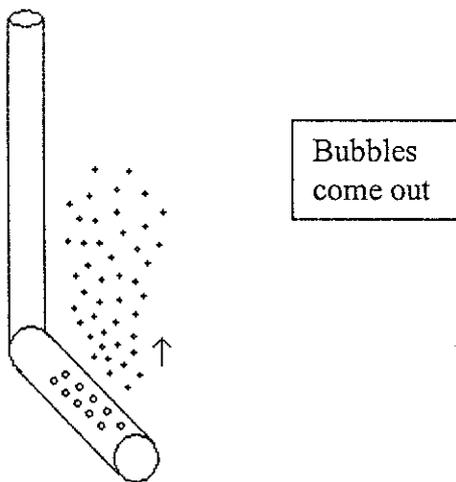


Figure 5.7.1 : Sparger tube diffuser

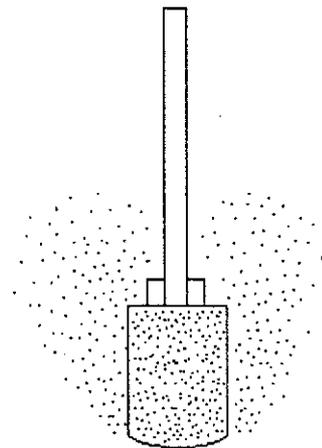


Figure 5.7.2 : Single Air stone diffuser

From both figures, the bubbles amount and bubble size which come out from the diffusers are different. In diffused aeration, oxygen transfer occurs during bubbles formation, during the bubble's ascent to the surface and at the water surface itself. James A.Muller, William C.oyle and H.Johannes stated that the rate of transfer is proportional to the area of contact between the liquid and the oxygen. This is the basic advantage of small bubbles. For example, 0.03 cu m (1 cu ft) of air in one bubble would have only 0.46m² of contact area, but when divided into bubbles of the size commonly produced by porous diffuser, 2 to 3 mm diameter, the same volume of air has about 65m² of contact area.

There seems, however, to be a limit to the effectiveness of decreasing bubbles size. Barnhart found that overall gas transfer coefficient K increased while bubble size decreased until the bubble diameter approach 2.2 mm, but further reduction of bubble size resulted in decreasing K . Although smaller bubble may increase the oxygen transfer efficiency, the additional power required to offset the increased headloss across the diffuser may negate any potential savings.[Ewing and Redmont 1981].

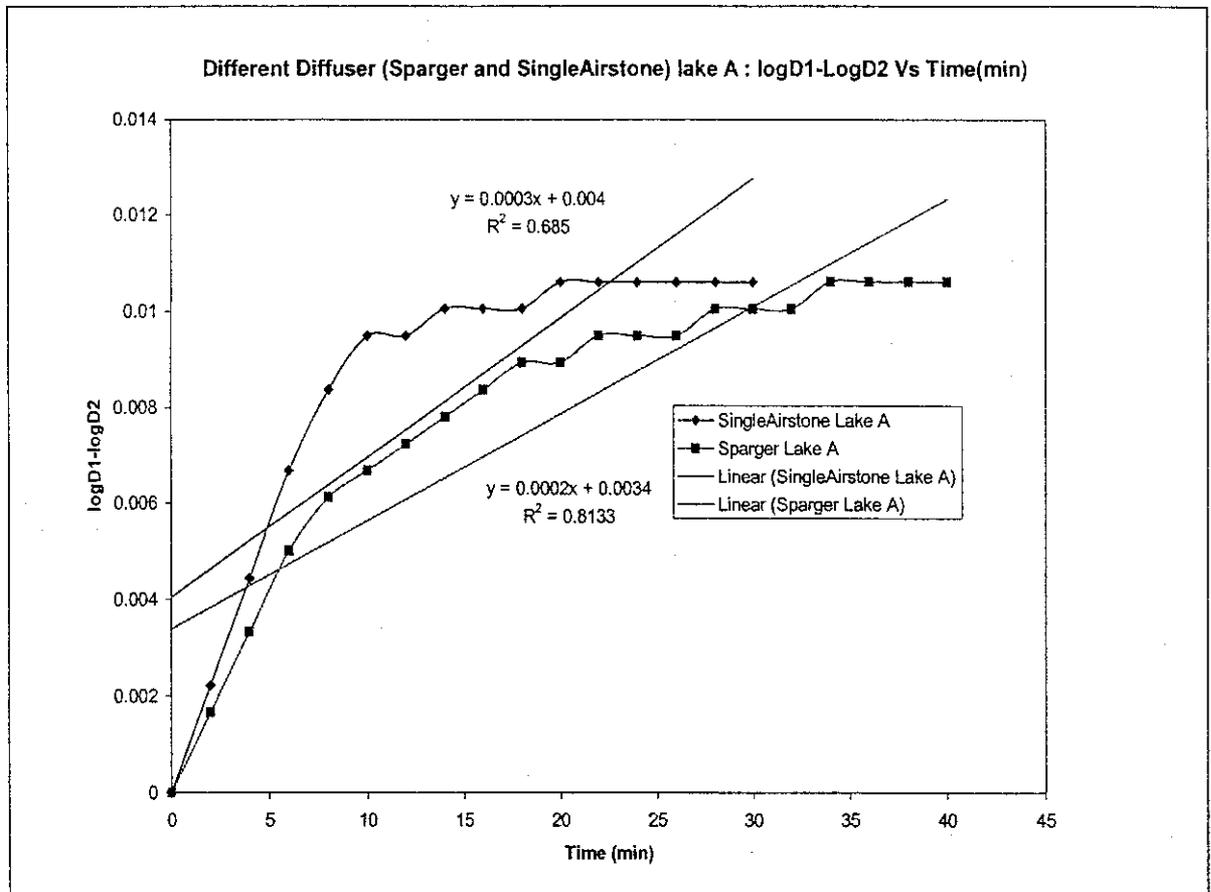


Figure 5.8 : Comparison of slope for different diffuser arrangement of Lake A

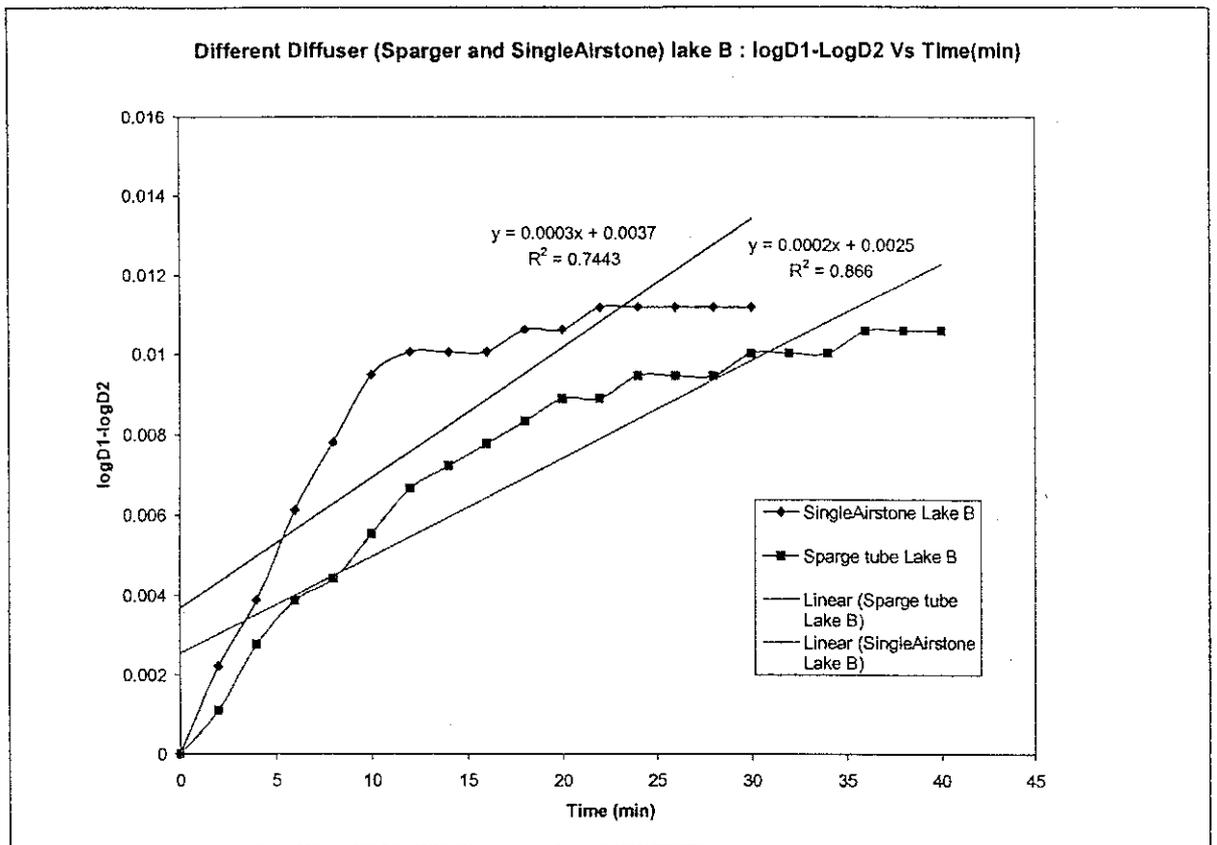


Figure 5.9 : Comparison of slope for different diffuser arrangement of Lake B

From the graph 5.8 and 5.9, single air stone diffuser shows higher slope 0.0003 compared to sparger tube diffuser 0.0002. The bubbles amount and bubbles size have affected the K value as discussed above. H.J. Popel and M. Wagner found that when the K value increase, The oxygenation capacity R also increase. The linear relation of K and R value has been discussed in previous objective.

5.2 Further Related Discussion

5.2.1 Bubbles Transfer rate

The bubble-transfer rate involves some additional considerations. Holroyd and H.B. Parker stated that liquid-phase equilibrium concentration of a given bubble is not only a function of temperature and atmospheric pressure, but also hydrostatic pressure and gas-phase oxygen composition.

As bubbles rise, bubble-water gas transfer of oxygen, nitrogen, argon, carbon dioxide, and trace gases occurs due to a concentration gradient between the equilibrium bubble concentration and the ambient water concentration. Over depth, the bubble-water transfer of all gases affects the gas-phase oxygen composition and the equilibrium oxygen concentration. The equilibrium oxygen concentration inside a bubble also depends on gas flow rate and the changing bubble-water transfer coefficient over depth.

5.2.2 The Constantacy of Absorption Coefficient, *K* Value

The *K* value depends on the region of oxygen transfer at the water surface. Oxygen transfer occurs as bubbles burst in the surfacing bubble plume. Transfer also occurs outside of the bubble plume across the surrounding water surface due to turbulence induced by bubble-plume motion and water circulation. Since the surface mass transfer rate coefficient depends on the level of turbulence produced at the water surface, *K* is generally believed to vary somewhat between the turbulent region of the surfacing bubble plume and the less turbulent region surrounding the bubble plume. But the difference is too small and could be considerably constant. . [Fischer HB, List JE, Koh RCY, Imberger J, Brooks, Acedemy Press 1979].

A constant bubble, *K* value over depth is assumed, which should be reasonable if plume turbulence does not vary greatly with depth. The bubble size and surface area, however, change during bubble rise due to pressure reduction, bubble splitting and coalescence,

and oxygen and nitrogen mass transfer into and out of the bubble. Since the changing bubble size is important but difficult to measure, a single bulk bubble-transfer coefficient, K_b , to represent the rate of oxygen transfer throughout the entire water depth has been used in many research before . Thus, the investigations of transfer coefficients K have assumed that the coefficient is constant in the integration .

CHAPTER 6

CONCLUSION AND RECOMMENDATION

From the project, several conclusions have been identified regarding the w10 equipment, K value behavior and R value behavior. The first and foremost conclusion can be made from both lake A and lake B is, lake A consume less oxygen compared to lake B due to higher Biological Oxygen Demand (BOD) in lake B. It is found that K value considerably constant as physical and chemical properties stay the same.

From the comparison experiment between clean water and wastewater, K value for wastewater is lower than clean water. From objective 5.1.2 and 5.1.3, it shows that K value does not change significantly by changing the airflow rate and so water depth. But for effect study on water depth itself, oxygen is easier to dissolve in lower water depth due to high turbulence flow and deeper oxygen probe positioning. Bubbles surface area and bubbles amount really make sense on K value. The smaller the bubble size and the larger the bubbles amount, will result in decreasing K value. It is proved in objective 5.1.5 different diffuser arrangement.

From objective 5.1.2, it can be concluded that the higher the average temperature, the lower the oxygenation capacity R in the samples. The R value is only affected by variation average temperature and K value. R value for clean water is higher than wastewater.

For recommendation, diffused air system performance cannot be compared since only one type of equipment is used. The suitable dissolve oxygen rate for required type of wastewater can be better known by testing it in different type of diffused air system equipment. Other things are, Standardized characteristic to differentiate wastewater and clean water should be introduced globally since until now there is no specific standard to defined clean water, and also fine bubbles and coarse bubbles application to porous and non porous diffuser respectively should be well defined. By only considering the bubbles

size is not enough because non porous diffuser can also produced the coarse bubble with fine bubbles size.

There are a lot of things can be studied regarding the aeration phenomenon. In the future, the scope of objective could be to study the effect of airflow rate per diffuser on standard oxygen transfer efficiency (SOTE) for different type of diffusers. As well as to study the effect of water depth on standard oxygen transfer efficiency for different diffused system. Study on standard aeration efficiency is also related to different airflow rate and different water depth.

Bubble-water transfer contributes significantly to the total oxygen transfer in diffused aeration system. Bubble-water transfer, however, is the dominant means of oxygen transfer. These results were obtained numerically and verified experimentally. The results can be applied to aerated systems at similar depths or to deeper water systems where the higher bubble-water concentration gradient near the submerged diffuser should cause an even greater dominance of bubble transfer in the aeration process. Insight into the relative importance of transfer across the water surface and bubble surface can be used to design more effective diffused aeration systems for lakes, reservoirs, and wastewater treatment facilities at a variety of water depths. A lake or reservoir will have a surface area that is much greater than the experiments herein. Application of these results to lakes and reservoirs requires a further analysis to investigate the oxygen transfer caused by bubbles-water transfer.

REFERNCES

1. "Aeration in Wastewater Treatment" Annual of Practise No 5, water Pollut. Control Fed., Washington,D.C (1971,1952).
2. Roe,F.C., "The Installation and Servicing of Air Diffused ediums". Water and Sewere orks. 81,1934,115-123.
3. U.S EPA and ASCE,; Summary Report : "Fine Pore (Fine Bubbles) Aeration System." EPA-625/8-85-010,Water Engineering.
4. Bartholomew,G.L, "Types of Aeration Devices." In: Aeration of Activated Sludge in Sewage Treatment.D.L Gibbon,(ED) 25-27, Pergamon Press,Inc., New York (1974).
5. Safe water From Every Tap : Improving Water Service To Small Communities (1996); Comission on Geoscienes, Environment and Resources.
6. Mohd Redzuan Bin Mansor and Abdul Malik, Engineering Team Project: Water Treatment; 2002.
7. AERATION: Principles and Practice., Water Quality Management Library, by W.W Eckenfelder,J.F Malina Jr. and J.W Patterson, 2002.
8. APHA,AWWA,WEF, Standard Methods for the Examination of Water and Wastewater, 18th edition, 1992.
9. ASCE Oxygen Transfer Standards Committee,"Development of Standard Procedures for Evaluating Oxygen Transfer Devices, "EPA-600/2-83-102, American Society of Civil Engineers, New York, 1983.
10. Rittman,B.E. and P.L McCarty (2001) Environmental Biotechnology: Principles and Applications, Mcgraw-Hill, Inc., New York.
11. Tchobanoglous, G., Burton, F.L., and Stensel D.H. (2003 astewater Engineering: Treatment and reuse, McGraw-Hill, inc., New York.
12. ASCE(1992) Standard-Measurement of Oxygen Transfer in Clean Water, ANSI/ASCE 2-91, 2nd ed.Reston, VA.

13. Operation Manual for YSI 550 Handheld Dissolve Oxygen and Temperature system YSI Incorporated. Pp. 1-27.
14. pr-European Standard: Wastewater Treatment Plant – part 15 : Measurement of Oxygen Transfer in Clean water and Activated Sludge in Aeratio Tank: pp. 1-17.1996
- 15.. Egan-Benck, K.; G. McCarty; and W.Winkler. 1993. "Choosing Diffusers."Water Environment and Technology. vol. 5. no. 2.pp. 54–59.
- 16.. McCarthy, J. 1982. "Technology Assessment of Fine Bubble Aerators." U.S. Environmental Protection Agency (EPA) Wastewater Research Division. Municipal Environmental Research Laboratory.Cincinnati, Ohio.
17. U.S. EPA, 1995. *Technological Assessment of Fine Bubble Aerators* EPA-600/2-82-003.
18. Metcalf & Eddy, Inc. 1991. Wastewater Engineering: Treatment, Disposal, and Reuse. 3d ed. The McGraw-Hill Companies. New York, New York.
19. U.S. EPA, 1985. *Summary Report: Fine Pore (Fine Bubble) Aeration Systems*. EPA Water Engineering Research Laboratory. Cincinnati, Ohio. EPA/625/8-85/010.
20. U. S. EPA, 1989. *Design Manual: Fine Pore Aeration Systems*. EPA Center for Environmental Research Information.Cincinnati, Ohio. EPA/625/1-89/023.
21. Armfield Limited Bridge House West Street Ringwood Hampshire England BH24 1DY.
22. Armfield Inc. 436 West Commodore Blvd (#2), Jackson NJ 08527.
23. Metcalf & Eddy, Inc. 1991. Wastewater Engineering: Treatment, Disposal, and Reuse. 3d ed. The McGraw-Hill Companies. New York, New York.
24. 1989. Design Manual: Fine Pore Aeration Systems. EPA Center for Environmental Research Information. Cincinnati, Ohio. EPA/625/1-89/023.
25. Department of Chemical Engineering, Tatung University, 40 Chungshan North Road, 3rd Sec., Taipei, 10451 Taiwan.
26. C., Comeau, Y. and Ton-That, Q.A., 1998. Alpha correction factors for static aerators and fine bubble diffusers used in municipal facultative aerated lagoons. Wat. Sc. Technol. 38, pp. 79-85.

27. J.-M. and Yu, C.-F., 1995. Volatile organic compound emission rate from diffused aeration systems. 1. Mass transfer modeling. *Ind. Engng. Chem. Res.* 34, pp. 2634–2643.
28. M. L. and Boyle W. C. (1985) Transfer of clean to dirty water oxygen transfer rate. In *Proceed. Seminar Workshop on Aeration System Design, Testing, Operation, and Control*, ed. W. C. Boyle, EPA-60019-85-005, Cincinnati, OH.
29. M.K. and Gilbert, R.G., 1981. Effects of alpha, beta, and theta factor upon the design, specification and operation of aeration systems. *Wat. Res.* 15, pp. 643–654.
30. H.J. Popel and M. Wagner, Modeling of oxygen transfer in deep diffused-aeration tanks and comparison with full-scale plant data. *Water Sci Tech* 30 4 (1994), pp.71–80.
31. A. Holroyd and H.B. Parker, Investigations on the dynamics of aeration. *J. Inst. of Sewage Purification* 3 (1949), p. 292.
32. W.D. Scouller and W. Watson, Solution of oxygen from air bubbles. *Surveyor* 86 2215 (1934), pp. 15–16.
33. A. Pasveer, Oxygenation of water with air bubbles. *Sewage Ind Wastes* 27 (1955), pp. 1130–1146.
34. M. Motarjemi and G.J. Jameson, Mass transfer from very small bubbles the optimum bubble size for aeration. *Chem Eng Sci* 33 (1978), pp. 1415–1423.

APPENDICES

APPENDICE A : EXPERIMENTAL RAW DATA
APPENDICES B : EXPERIMENTAL CALCULATION
APPENDICES C : TABLE OF CORRECTION FACTOR

Time(min)	C=O ₂ (mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=C _s -C ₀	D2=C _s -C ₁	Log D1	Log D2	LogD1-LogD2
0	0.01	28.4	28.175	7.874	7.864	7.864	0.895643505	0.895643505	0
2	0.04	28.4	28.175	7.874	7.864	7.834	0.895643505	0.893983567	0.001659938
4	0.07	28.3	28.175	7.874	7.864	7.804	0.895643505	0.892317261	0.003326244
6	0.1	28.3	28.175	7.874	7.864	7.774	0.895643505	0.890644536	0.004998969
8	0.12	28.3	28.175	7.874	7.864	7.754	0.895643505	0.889525797	0.006117708
10	0.13	28.3	28.175	7.874	7.864	7.744	0.895643505	0.888965344	0.006678161
12	0.14	28.2	28.175	7.874	7.864	7.734	0.895643505	0.888404168	0.007239337
14	0.15	28.2	28.175	7.874	7.864	7.724	0.895643505	0.887842265	0.00780124
16	0.16	28.2	28.175	7.874	7.864	7.714	0.895643505	0.887279635	0.00836387
18	0.17	28.2	28.175	7.874	7.864	7.704	0.895643505	0.886716274	0.008927231
20	0.17	28.2	28.175	7.874	7.864	7.704	0.895643505	0.886716274	0.008927231
22	0.18	28.2	28.175	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
24	0.18	28.1	28.175	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
26	0.18	28.1	28.175	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
28	0.19	28.1	28.175	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
30	0.19	28.1	28.175	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
32	0.19	28.1	28.175	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
34	0.2	28	28.175	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
36	0.2	28	28.175	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
38	0.2	28	28.175	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
40	0.2	28	28.175	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171

Table 1.0: Non steady State Condition (Lake A) – Flowrate 4 L/Min

Time(min)	C=O ₂ (mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=C _s -C ₀	D2=C _s -C ₁	Log D1	Log D2	LogD1-LogD2
0	0.01	28.1	28.043	7.894	7.884	7.884	0.896746616	0.896746616	0
2	0.03	28.1	28.043	7.894	7.884	7.864	0.896746616	0.895643505	0.001103111
4	0.06	28.1	28.043	7.894	7.884	7.834	0.896746616	0.893983567	0.002763048
6	0.08	28.1	28.043	7.894	7.884	7.814	0.896746616	0.892873407	0.003873209
8	0.09	28.1	28.043	7.894	7.884	7.804	0.896746616	0.892317261	0.004429355
10	0.11	28.1	28.043	7.894	7.884	7.784	0.896746616	0.891202827	0.005543788
12	0.13	28.1	28.043	7.894	7.884	7.764	0.896746616	0.890085527	0.006661089
14	0.14	28.1	28.043	7.894	7.884	7.754	0.896746616	0.889525797	0.007220819
16	0.15	28.1	28.043	7.894	7.884	7.744	0.896746616	0.888965344	0.007781271
18	0.16	28	28.043	7.894	7.884	7.734	0.896746616	0.888404168	0.008342448
20	0.17	28	28.043	7.894	7.884	7.724	0.896746616	0.887842265	0.008904351
22	0.17	28	28.043	7.894	7.884	7.724	0.896746616	0.887842265	0.008904351
24	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
26	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
28	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
30	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
32	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
34	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
36	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434
38	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434
40	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434

Table 2.0 : Non Steady State Condition (Lake B) – Flowrate 4 L/Min

me(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.01	28.4	28.175	7.874	7.864	7.864	0.895643505	0.895643505	0
2	0.04	28.4	28.175	7.874	7.864	7.834	0.895643505	0.893983567	0.001659938
4	0.07	28.3	28.175	7.874	7.864	7.804	0.895643505	0.892317261	0.003326244
6	0.1	28.3	28.175	7.874	7.864	7.774	0.895643505	0.890644536	0.004998969
8	0.12	28.3	28.175	7.874	7.864	7.754	0.895643505	0.889525797	0.006117708
10	0.13	28.3	28.175	7.874	7.864	7.744	0.895643505	0.888965344	0.006678161
12	0.14	28.2	28.175	7.874	7.864	7.734	0.895643505	0.888404168	0.007239337
14	0.15	28.2	28.175	7.874	7.864	7.724	0.895643505	0.887842265	0.00780124
16	0.16	28.2	28.175	7.874	7.864	7.714	0.895643505	0.887279635	0.00836387
18	0.17	28.2	28.175	7.874	7.864	7.704	0.895643505	0.886716274	0.008927231
20	0.17	28.2	28.175	7.874	7.864	7.704	0.895643505	0.886716274	0.008927231
22	0.18	28.2	28.175	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
24	0.18	28.1	28.175	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
26	0.18	28.1	28.175	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
28	0.19	28.1	28.175	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
30	0.19	28.1	28.175	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
32	0.19	28.1	28.175	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
34	0.2	28	28.175	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
36	0.2	28	28.175	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
38	0.2	28	28.175	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
40	0.2	28	28.175	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171

Table 1.1 : Different Air Flowrate (Lake A) – 4 L/Min

Time(min)	O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.05	27.5	27.5	7.975	7.925	7.925	0.898999271	0.898999271	0
2	0.09	27.5	27.5	7.975	7.925	7.885	0.898999271	0.896801698	0.002197573
4	0.12	27.5	27.5	7.975	7.925	7.855	0.898999271	0.895146189	0.003853082
6	0.14	27.5	27.5	7.975	7.925	7.835	0.898999271	0.894039001	0.00496027
8	0.15	27.5	27.5	7.975	7.925	7.825	0.898999271	0.893484346	0.005514925
10	0.17	27.5	27.5	7.975	7.925	7.805	0.898999271	0.892372907	0.006626363
12	0.17	27.5	27.5	7.975	7.925	7.805	0.898999271	0.892372907	0.006626363
14	0.18	27.5	27.5	7.975	7.925	7.795	0.898999271	0.89181612	0.007183151
16	0.19	27.5	27.5	7.975	7.925	7.785	0.898999271	0.891258617	0.007740654
18	0.19	27.5	27.5	7.975	7.925	7.785	0.898999271	0.891258617	0.007740654
20	0.2	27.5	27.5	7.975	7.925	7.775	0.898999271	0.890700398	0.008298873
22	0.2	27.5	27.5	7.975	7.925	7.775	0.898999271	0.890700398	0.008298873
24	0.2	27.5	27.5	7.975	7.925	7.775	0.898999271	0.890700398	0.008298873
26	0.21	27.5	27.5	7.975	7.925	7.765	0.898999271	0.89014146	0.008857811
28	0.21	27.5	27.5	7.975	7.925	7.765	0.898999271	0.89014146	0.008857811
30	0.21	27.5	27.5	7.975	7.925	7.765	0.898999271	0.89014146	0.008857811
32	0.21	27.5	27.5	7.975	7.925	7.765	0.898999271	0.89014146	0.008857811
34	0.21	27.5	27.5	7.975	7.925	7.765	0.898999271	0.89014146	0.008857811
36	0.21	27.5	27.5	7.975	7.925	7.765	0.898999271	0.89014146	0.008857811
38	0.21	27.5	27.5	7.975	7.925	7.765	0.898999271	0.89014146	0.008857811
40	0.21	27.5	27.5	7.975	7.925	7.765	0.898999271	0.89014146	0.008857811

Table 1.2 : Different Air Flowrate (Lake A) – 8 L/Min

Table 1.3 : Different Air Flowrate (Lake A) – 12 L/Min

Time(min)	O ₂ (mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs- C0	D2=Cs- C1	Log D1	Log D2	LogD1- LogD2
0	0.06	31.2	30.925	7.461	7.401	7.401	0.869	0.869	0
2	0.1	31.2	30.925	7.461	7.401	7.361	0.869	0.867	0.002353586
4	0.13	31.2	30.925	7.461	7.401	7.331	0.869	0.865	0.004127185
6	0.15	31.2	30.925	7.461	7.401	7.311	0.869	0.864	0.00531362
8	0.17	31.1	30.925	7.461	7.401	7.291	0.869	0.863	0.006503306
10	0.18	31.1	30.925	7.461	7.401	7.281	0.869	0.862	0.007099373
12	0.18	31.1	30.925	7.461	7.401	7.281	0.869	0.862	0.007099373
14	0.19	30.8	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626
16	0.19	30.8	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626
18	0.19	30.8	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626
20	0.19	30.8	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626
22	0.19	30.7	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626
24	0.19	30.7	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626
26	0.19	30.7	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626
28	0.19	30.7	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626
30	0.19	30.7	30.925	7.461	7.401	7.271	0.869	0.862	0.00769626

Table 1.4 : Different Depth (Lake A) – 100mm

Time(min)	C=O2(mg/l)	Temp.	Avrg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.02	23.1	23.1	8.635	8.615	8.615	0.935255282	0.935255282	0
2	0.06	23.1	23.1	8.635	8.615	8.575	0.935255282	0.933234129	0.002021153
4	0.09	23.1	23.1	8.635	8.615	8.545	0.935255282	0.931712067	0.003543215
6	0.12	23.1	23.1	8.635	8.615	8.515	0.935255282	0.930184652	0.005070629
8	0.14	23.1	23.1	8.635	8.615	8.495	0.935255282	0.929163383	0.006091899
10	0.15	23.1	23.1	8.635	8.615	8.485	0.935255282	0.928651847	0.006603435
12	0.16	23.1	23.1	8.635	8.615	8.475	0.935255282	0.928139707	0.007115575
14	0.17	23.1	23.1	8.635	8.615	8.465	0.935255282	0.927626962	0.007628319
16	0.18	23.1	23.1	8.635	8.615	8.455	0.935255282	0.927113612	0.00814167
18	0.18	23.1	23.1	8.635	8.615	8.455	0.935255282	0.927113612	0.00814167
20	0.18	23.1	23.1	8.635	8.615	8.455	0.935255282	0.927113612	0.00814167
22	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
24	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
26	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
28	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
30	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
32	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
34	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
36	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
38	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628
40	0.19	23.1	23.1	8.635	8.615	8.445	0.935255282	0.926599654	0.008655628

Table 1.5 : Different Depth (Lake A) – 200mm

Time(min)	C=O2(mg/l)	Temp.	Avrg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.01	23.3	23.3	8.605	8.595	8.595	0.934245881	0.934245881	0
2	0.04	23.3	23.3	8.605	8.595	8.565	0.934245881	0.932727367	0.001518514
4	0.06	23.3	23.3	8.605	8.595	8.545	0.934245881	0.931712067	0.002533814
6	0.08	23.3	23.3	8.605	8.595	8.525	0.934245881	0.930694388	0.003551493
8	0.11	23.3	23.3	8.605	8.595	8.495	0.934245881	0.929163383	0.005082498
10	0.12	23.3	23.3	8.605	8.595	8.485	0.934245881	0.928651847	0.005594034
12	0.14	23.3	23.3	8.605	8.595	8.465	0.934245881	0.927626962	0.006618919
14	0.15	23.3	23.3	8.605	8.595	8.455	0.934245881	0.927113612	0.007132269
16	0.16	23.3	23.3	8.605	8.595	8.445	0.934245881	0.926599654	0.007646227
18	0.17	23.3	23.3	8.605	8.595	8.435	0.934245881	0.926085087	0.008160794
20	0.18	23.3	23.3	8.605	8.595	8.425	0.934245881	0.92556991	0.008675971
22	0.18	23.3	23.3	8.605	8.595	8.425	0.934245881	0.92556991	0.008675971
24	0.18	23.3	23.3	8.605	8.595	8.425	0.934245881	0.92556991	0.008675971
26	0.18	23.3	23.3	8.605	8.595	8.425	0.934245881	0.92556991	0.008675971
28	0.19	23.3	23.3	8.605	8.595	8.415	0.934245881	0.92505412	0.009191761
30	0.19	23.3	23.3	8.605	8.595	8.415	0.934245881	0.92505412	0.009191761
32	0.2	23.3	23.3	8.605	8.595	8.405	0.934245881	0.924537718	0.009708163
34	0.2	23.3	23.3	8.605	8.595	8.405	0.934245881	0.924537718	0.009708163
36	0.2	23.3	23.3	8.605	8.595	8.405	0.934245881	0.924537718	0.009708163
38	0.2	23.3	23.3	8.605	8.595	8.405	0.934245881	0.924537718	0.009708163
40	0.2	23.3	23.3	8.605	8.595	8.405	0.934245881	0.924537718	0.009708163

Table 1.6 : Different Depth (Lake A) – 300mm

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	LogD1	LogD2	LogD1-LogD2
0	0.01	28.4	28.176	7.874	7.864	7.864	0.895643505	0.895643505	0
2	0.04	28.4	28.176	7.874	7.864	7.834	0.895643505	0.893983567	0.001659938
4	0.07	28.3	28.176	7.874	7.864	7.804	0.895643505	0.892317261	0.003326244
6	0.1	28.3	28.176	7.874	7.864	7.774	0.895643505	0.890644536	0.004998969
8	0.12	28.3	28.176	7.874	7.864	7.754	0.895643505	0.889525797	0.006117708
10	0.13	28.3	28.176	7.874	7.864	7.744	0.895643505	0.888965344	0.006678161
12	0.14	28.2	28.176	7.874	7.864	7.734	0.895643505	0.888404168	0.007239337
14	0.15	28.2	28.176	7.874	7.864	7.724	0.895643505	0.887842265	0.00780124
16	0.16	28.2	28.176	7.874	7.864	7.714	0.895643505	0.887279635	0.00836387
18	0.17	28.2	28.176	7.874	7.864	7.704	0.895643505	0.886716274	0.008927231
20	0.17	28.2	28.176	7.874	7.864	7.704	0.895643505	0.886716274	0.008927231
22	0.18	28.2	28.176	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
24	0.18	28.1	28.176	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
26	0.18	28.1	28.176	7.874	7.864	7.694	0.895643505	0.886152182	0.009491323
28	0.19	28.1	28.176	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
30	0.19	28.1	28.176	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
32	0.19	28.1	28.176	7.874	7.864	7.684	0.895643505	0.885587356	0.010056149
34	0.2	28	28.176	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
36	0.2	28	28.176	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
38	0.2	28	28.176	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171
40	0.2	28	28.176	7.874	7.864	7.674	0.895643505	0.885021795	0.01062171

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.02	28.2	28.075	7.889	7.869	7.869	0.895919545	0.895919545	0
2	0.06	28.2	28.075	7.889	7.869	7.829	0.895919545	0.893706293	0.002213252
4	0.1	28.2	28.075	7.889	7.869	7.789	0.895919545	0.891481704	0.004437841
6	0.14	28.1	28.075	7.889	7.869	7.749	0.895919545	0.889245661	0.006673884
8	0.17	28.1	28.075	7.889	7.869	7.719	0.895919545	0.887561041	0.008358504
10	0.19	28.1	28.075	7.889	7.869	7.699	0.895919545	0.88643432	0.009485226
12	0.19	28.1	28.075	7.889	7.869	7.699	0.895919545	0.88643432	0.009485226
14	0.2	28.1	28.075	7.889	7.869	7.689	0.895919545	0.885869861	0.010049684
16	0.2	28.1	28.075	7.889	7.869	7.689	0.895919545	0.885869861	0.010049684
18	0.2	28	28.075	7.889	7.869	7.689	0.895919545	0.885869861	0.010049684
20	0.21	28	28.075	7.889	7.869	7.679	0.895919545	0.885304668	0.010614878
22	0.21	28	28.075	7.889	7.869	7.679	0.895919545	0.885304668	0.010614878
24	0.21	28	28.075	7.889	7.869	7.679	0.895919545	0.885304668	0.010614878
26	0.21	28	28.075	7.889	7.869	7.679	0.895919545	0.885304668	0.010614878
28	0.21	28	28.075	7.889	7.869	7.679	0.895919545	0.885304668	0.010614878
30	0.21	28	28.075	7.889	7.869	7.679	0.895919545	0.885304668	0.010614878

Table 1.7 : Diference Diffuser Arrangement (Lake A) – single airstone

Table 2.1 : Different Flowrate (Lake B) – 4 L/Min

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.01	28.1	28.043	7.894	7.884	7.884	0.896746616	0.896746616	0
2	0.03	28.1	28.043	7.894	7.884	7.864	0.896746616	0.895643505	0.001103111
4	0.06	28.1	28.043	7.894	7.884	7.834	0.896746616	0.893983567	0.002763048
6	0.08	28.1	28.043	7.894	7.884	7.814	0.896746616	0.892873407	0.003873209
8	0.09	28.1	28.043	7.894	7.884	7.804	0.896746616	0.892317261	0.004429355
10	0.11	28.1	28.043	7.894	7.884	7.784	0.896746616	0.891202827	0.005543788
12	0.13	28.1	28.043	7.894	7.884	7.764	0.896746616	0.890085527	0.006661089
14	0.14	28.1	28.043	7.894	7.884	7.754	0.896746616	0.889525797	0.007220819
16	0.15	28.1	28.043	7.894	7.884	7.744	0.896746616	0.888965344	0.007781271
18	0.16	28	28.043	7.894	7.884	7.734	0.896746616	0.888404168	0.008342448
20	0.17	28	28.043	7.894	7.884	7.724	0.896746616	0.887842265	0.008904351
22	0.17	28	28.043	7.894	7.884	7.724	0.896746616	0.887842265	0.008904351
24	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
26	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
28	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
30	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
32	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
34	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
36	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434
38	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434
40	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434

Table 2.2 : Different Flowrate (Lake B) – 8 L/Min

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.04	27.7	27.624	7.956	7.916	7.916	0.898505786	0.898505786	0
2	0.07	27.7	27.624	7.956	7.916	7.886	0.898505786	0.896856773	0.001649013
4	0.11	27.7	27.624	7.956	7.916	7.846	0.898505786	0.894648304	0.003857482
6	0.13	27.7	27.624	7.956	7.916	7.826	0.898505786	0.893539844	0.004965942
8	0.15	27.7	27.624	7.956	7.916	7.806	0.898505786	0.892428547	0.006077239
10	0.16	27.7	27.624	7.956	7.916	7.796	0.898505786	0.89187183	0.006633955
12	0.17	27.7	27.624	7.956	7.916	7.786	0.898505786	0.891314399	0.007191386
14	0.18	27.7	27.624	7.956	7.916	7.776	0.898505786	0.890756252	0.007749534
16	0.18	27.6	27.624	7.956	7.916	7.776	0.898505786	0.890756252	0.007749534
18	0.18	27.6	27.624	7.956	7.916	7.776	0.898505786	0.890756252	0.007749534
20	0.19	27.6	27.624	7.956	7.916	7.766	0.898505786	0.890197386	0.008308399
22	0.19	27.6	27.624	7.956	7.916	7.766	0.898505786	0.890197386	0.008308399
24	0.19	27.6	27.624	7.956	7.916	7.766	0.898505786	0.890197386	0.008308399
26	0.2	27.6	27.624	7.956	7.916	7.756	0.898505786	0.8896378	0.008867985
28	0.2	27.6	27.624	7.956	7.916	7.756	0.898505786	0.8896378	0.008867985
30	0.2	27.6	27.624	7.956	7.916	7.756	0.898505786	0.8896378	0.008867985
32	0.21	27.6	27.624	7.956	7.916	7.746	0.898505786	0.889077493	0.009428293
34	0.21	27.6	27.624	7.956	7.916	7.746	0.898505786	0.889077493	0.009428293
36	0.21	27.5	27.624	7.956	7.916	7.746	0.898505786	0.889077493	0.009428293
38	0.21	27.5	27.624	7.956	7.916	7.746	0.898505786	0.889077493	0.009428293
40	0.21	27.5	27.624	7.956	7.916	7.746	0.898505786	0.889077493	0.009428293

Table 2.3 : Different Flowrate (Lake B) – 12 L/Min

Time(min)	O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs- C0	D2=Cs- C1	Log D1	Log D2	LogD1- LogD2
0	0.05	32.2	32.025	7.396	7.346	7.346	0.866	0.866	0
2	0.09	32.2	32.025	7.396	7.346	7.306	0.866	0.864	0.002371256
4	0.13	32.2	32.025	7.396	7.346	7.266	0.866	0.861	0.00475553
6	0.16	32.2	32.025	7.396	7.346	7.236	0.866	0.859	0.006552366
8	0.17	32.2	32.025	7.396	7.346	7.226	0.866	0.859	0.007152967
10	0.17	32.2	32.025	7.396	7.346	7.226	0.866	0.859	0.007152967
12	0.18	32.1	32.025	7.396	7.346	7.216	0.866	0.858	0.007754399
14	0.18	32.1	32.025	7.396	7.346	7.216	0.866	0.858	0.007754399
16	0.18	32	32.025	7.396	7.346	7.216	0.866	0.858	0.007754399
18	0.18	32	32.025	7.396	7.346	7.216	0.866	0.858	0.007754399
20	0.19	32	32.025	7.396	7.346	7.206	0.866	0.858	0.008356666
22	0.19	31.8	32.025	7.396	7.346	7.206	0.866	0.858	0.008356666
24	0.19	31.8	32.025	7.396	7.346	7.206	0.866	0.858	0.008356666
26	0.19	31.8	32.025	7.396	7.346	7.206	0.866	0.858	0.008356666
28	0.19	31.8	32.025	7.396	7.346	7.206	0.866	0.858	0.008356666
30	0.19	31.8	32.025	7.396	7.346	7.206	0.866	0.858	0.008356666

Table 2.4 : Different Depth (Lake B) – 100mm

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.01	28	27.89	7.917	7.907	7.907	0.898011739	0.898011739	0
2	0.04	28	27.89	7.917	7.907	7.877	0.898011739	0.896360845	0.001650893
4	0.07	28	27.89	7.917	7.907	7.847	0.898011739	0.894703653	0.003308086
6	0.1	28	27.89	7.917	7.907	7.817	0.898011739	0.893040112	0.004971627
8	0.12	28	27.89	7.917	7.907	7.797	0.898011739	0.891927534	0.006084205
10	0.13	27.9	27.89	7.917	7.907	7.787	0.898011739	0.891370175	0.006641564
12	0.14	27.9	27.89	7.917	7.907	7.777	0.898011739	0.890812099	0.00719964
14	0.15	27.9	27.89	7.917	7.907	7.767	0.898011739	0.890253305	0.007758434
16	0.16	27.9	27.89	7.917	7.907	7.757	0.898011739	0.889693791	0.008317947
18	0.17	27.9	27.89	7.917	7.907	7.747	0.898011739	0.889133556	0.008878183
20	0.18	27.9	27.89	7.917	7.907	7.737	0.898011739	0.888572597	0.009439142
22	0.18	27.9	27.89	7.917	7.907	7.737	0.898011739	0.888572597	0.009439142
24	0.18	27.9	27.89	7.917	7.907	7.737	0.898011739	0.888572597	0.009439142
26	0.18	27.9	27.89	7.917	7.907	7.737	0.898011739	0.888572597	0.009439142
28	0.19	27.8	27.89	7.917	7.907	7.727	0.898011739	0.888010912	0.010000827
30	0.19	27.8	27.89	7.917	7.907	7.727	0.898011739	0.888010912	0.010000827
32	0.19	27.8	27.89	7.917	7.907	7.727	0.898011739	0.888010912	0.010000827
34	0.19	27.8	27.89	7.917	7.907	7.727	0.898011739	0.888010912	0.010000827
36	0.19	27.8	27.89	7.917	7.907	7.727	0.898011739	0.888010912	0.010000827
38	0.19	27.8	27.89	7.917	7.907	7.727	0.898011739	0.888010912	0.010000827
40	0.19	27.8	27.89	7.917	7.907	7.727	0.898011739	0.888010912	0.010000827

Table 2.5 : Different Depth (Lake B) – 200mm

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.01	27.5	27.43	7.986	7.976	7.976	0.901785145	0.901785145	0
2	0.03	27.5	27.43	7.986	7.976	7.956	0.901785145	0.900694774	0.001090371
4	0.05	27.5	27.43	7.986	7.976	7.936	0.901785145	0.899601659	0.002183486
6	0.08	27.5	27.43	7.986	7.976	7.906	0.901785145	0.89795681	0.003828335
8	0.1	27.5	27.43	7.986	7.976	7.886	0.901785145	0.896856773	0.004928373
10	0.12	27.5	27.43	7.986	7.976	7.866	0.901785145	0.895753942	0.006031203
12	0.13	27.5	27.43	7.986	7.976	7.856	0.901785145	0.895201475	0.006583671
14	0.14	27.5	27.43	7.986	7.976	7.846	0.901785145	0.894648304	0.007136842
16	0.15	27.5	27.43	7.986	7.976	7.836	0.901785145	0.894094427	0.007690718
18	0.16	27.4	27.43	7.986	7.976	7.826	0.901785145	0.893539844	0.008245302
20	0.17	27.4	27.43	7.986	7.976	7.816	0.901785145	0.892984551	0.008800595
22	0.18	27.4	27.43	7.986	7.976	7.806	0.901785145	0.892428547	0.009356598
24	0.18	27.4	27.43	7.986	7.976	7.806	0.901785145	0.892428547	0.009356598
26	0.18	27.4	27.43	7.986	7.976	7.806	0.901785145	0.892428547	0.009356598
28	0.19	27.4	27.43	7.986	7.976	7.796	0.901785145	0.89187183	0.009913315
30	0.19	27.4	27.43	7.986	7.976	7.796	0.901785145	0.89187183	0.009913315
32	0.19	27.4	27.43	7.986	7.976	7.796	0.901785145	0.89187183	0.009913315
34	0.19	27.4	27.43	7.986	7.976	7.796	0.901785145	0.89187183	0.009913315
36	0.2	27.3	27.43	7.986	7.976	7.786	0.901785145	0.891314399	0.010470746
38	0.2	27.3	27.43	7.986	7.976	7.786	0.901785145	0.891314399	0.010470746
40	0.2	27.3	27.43	7.986	7.976	7.786	0.901785145	0.891314399	0.010470746

Table 2.6 : Different Depth (Lake B) – 300mm

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.01	28.1	28.043	7.894	7.884	7.884	0.896746616	0.896746616	0
2	0.03	28.1	28.043	7.894	7.884	7.864	0.896746616	0.895643505	0.001103111
4	0.06	28.1	28.043	7.894	7.884	7.834	0.896746616	0.893983567	0.002763048
6	0.08	28.1	28.043	7.894	7.884	7.814	0.896746616	0.892873407	0.003873209
8	0.09	28.1	28.043	7.894	7.884	7.804	0.896746616	0.892317261	0.004429355
10	0.11	28.1	28.043	7.894	7.884	7.784	0.896746616	0.891202827	0.005543788
12	0.13	28.1	28.043	7.894	7.884	7.764	0.896746616	0.890085527	0.006661089
14	0.14	28.1	28.043	7.894	7.884	7.754	0.896746616	0.889525797	0.007220819
16	0.15	28.1	28.043	7.894	7.884	7.744	0.896746616	0.888965344	0.007781271
18	0.16	28	28.043	7.894	7.884	7.734	0.896746616	0.888404168	0.008342448
20	0.17	28	28.043	7.894	7.884	7.724	0.896746616	0.887842265	0.008904351
22	0.17	28	28.043	7.894	7.884	7.724	0.896746616	0.887842265	0.008904351
24	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
26	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
28	0.18	28	28.043	7.894	7.884	7.714	0.896746616	0.887279635	0.009466981
30	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
32	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
34	0.19	28	28.043	7.894	7.884	7.704	0.896746616	0.886716274	0.010030341
36	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434
38	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434
40	0.2	28	28.043	7.894	7.884	7.694	0.896746616	0.886152182	0.010594434

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.01	28.3	28.2	7.87	7.86	7.86	0.895422546	0.895422546	0
2	0.05	28.3	28.2	7.87	7.86	7.82	0.895422546	0.893206753	0.002215793
4	0.08	28.3	28.2	7.87	7.86	7.79	0.895422546	0.891537458	0.003885088
6	0.12	28.3	28.2	7.87	7.86	7.75	0.895422546	0.889301703	0.006120844
8	0.15	28.3	28.2	7.87	7.86	7.72	0.895422546	0.8876173	0.007805246
10	0.18	28.2	28.2	7.87	7.86	7.69	0.895422546	0.88592634	0.009496206
12	0.19	28.2	28.2	7.87	7.86	7.68	0.895422546	0.88536122	0.010061326
14	0.19	28.2	28.2	7.87	7.86	7.68	0.895422546	0.88536122	0.010061326
16	0.19	28.2	28.2	7.87	7.86	7.68	0.895422546	0.88536122	0.010061326
18	0.2	28.2	28.2	7.87	7.86	7.67	0.895422546	0.884795364	0.010627182
20	0.2	28.2	28.2	7.87	7.86	7.67	0.895422546	0.884795364	0.010627182
22	0.21	28.1	28.2	7.87	7.86	7.66	0.895422546	0.88422877	0.011193776
24	0.21	28.1	28.2	7.87	7.86	7.66	0.895422546	0.88422877	0.011193776
26	0.21	28.1	28.2	7.87	7.86	7.66	0.895422546	0.88422877	0.011193776
28	0.21	28.1	28.2	7.87	7.86	7.66	0.895422546	0.88422877	0.011193776
30	0.21	28.1	28.2	7.87	7.86	7.66	0.895422546	0.88422877	0.011193776

Table 2.7 : Diference Diffuser Arrangement (Lake B) – Single Airstone

Table 3.0 : Diference waste material (clean water)

Time(min)	C=O2(mg/l)	Temp.	Avg.Temp	Cs mg/l	D1=Cs-C0	D2=Cs-C1	Log D1	Log D2	LogD1-LogD2
0	0.03	28.4	28.175	7.874	7.844	7.844	0.894537585	0.894537585	0
2	0.07	28.4	28.175	7.874	7.844	7.804	0.894537585	0.892317261	0.002220324
4	0.1	28.3	28.175	7.874	7.844	7.774	0.894537585	0.890644536	0.003893049
6	0.13	28.3	28.175	7.874	7.844	7.744	0.894537585	0.888965344	0.005572241
8	0.16	28.3	28.175	7.874	7.844	7.714	0.894537585	0.887279635	0.00725795
10	0.18	28.3	28.175	7.874	7.844	7.694	0.894537585	0.886152182	0.008385403
12	0.19	28.2	28.175	7.874	7.844	7.684	0.894537585	0.885587356	0.008950229
14	0.19	28.2	28.175	7.874	7.844	7.684	0.894537585	0.885587356	0.008950229
16	0.2	28.2	28.175	7.874	7.844	7.674	0.894537585	0.885021795	0.00951579
18	0.2	28.2	28.175	7.874	7.844	7.674	0.894537585	0.885021795	0.00951579
20	0.21	28.2	28.175	7.874	7.844	7.664	0.894537585	0.884455496	0.010082089
22	0.21	28.2	28.175	7.874	7.844	7.664	0.894537585	0.884455496	0.010082089
24	0.21	28.1	28.175	7.874	7.844	7.664	0.894537585	0.884455496	0.010082089
26	0.21	28.1	28.175	7.874	7.844	7.664	0.894537585	0.884455496	0.010082089
28	0.21	28.1	28.175	7.874	7.844	7.664	0.894537585	0.884455496	0.010082089
30	0.21	28.1	28.175	7.874	7.844	7.664	0.894537585	0.884455496	0.010082089

APPENDICE B

EXPERIMENTAL CALCULATION

Calculation

Non-stead State condition of lake A

1) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.6977)(0.0004606 \text{ mg/L}\cdot\text{min})(7.874)(20\text{L})(60 \text{ min/1hr})(1 \text{ g/1000mg})$$

$$= 0.003036 \text{ g/hr}$$

Air Flowrate 4 l/min of lake A

2) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.6977)(0.0004606 \text{ mg/L}\cdot\text{min})(7.874)(20\text{L})(60 \text{ min/1hr})(1 \text{ g/1000mg})$$

$$= 0.003036 \text{ g/hr}$$

Air Flowrate 8 l/min of lake A

3) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.707)(0.0004606 \text{ mg/L}\cdot\text{min})(7.975)(20\text{L})(60 \text{ min/1hr})(1 \text{ g/1000mg})$$

$$= 0.003116 \text{ g/hr}$$

Air Flowrate 12 l/min of lake A

4) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.6605)(0.0004606 \text{ mg/L}\cdot\text{min})(7.461)(20\text{L})(60 \text{ min/1hr})(1 \text{ g/1000mg})$$

$$= 0.002724 \text{ g/hr}$$

100mm depth of water sample of lake A (4 l/min)

5) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.7697)(0.0004606 \text{ mg/L}\cdot\text{min})(8.635)(20\text{L})(60 \text{ min}/1 \text{ hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003674 \text{ g/hr}$$

200mm depth of water sample of lake A (4 l/min)

6) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.7671)(0.0004606 \text{ mg/L}\cdot\text{min})(8.605)(20\text{L})(60 \text{ min}/1 \text{ hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003648 \text{ g/hr}$$

300mm depth of water sample of lake A (4 l/min)

7) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.6977)(0.0004606 \text{ mg/L}\cdot\text{min})(7.874)(20\text{L})(60 \text{ min}/1 \text{ hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003036 \text{ g/hr}$$

Diference diffuser Arrangement (lake A) – single airstone

8) Slope = 0.0003 mg/L·min

$$K_s = 2.303 \times 0.0003 \text{ mg/L}\cdot\text{min}$$

$$= 0.0006909 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.7135)(0.0006909 \text{ mg/L}\cdot\text{min})(7.889)(20\text{L})(60 \text{ min}/1 \text{ hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.00467 \text{ g/hr}$$

Non-stead State condition of lake B

1) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.6995)(0.0004606 \text{ mg/L}\cdot\text{min})(7.894)(20\text{L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003052 \text{ g/hr}$$

Air Flowrate 4 l/min of lake B

2) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.6995)(0.0004606 \text{ mg/L}\cdot\text{min})(7.894)(20\text{L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003052 \text{ g/hr}$$

Air Flowrate 8 l/min of lake B

3) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.7052)(0.0004606 \text{ mg/L}\cdot\text{min})(7.956)(20\text{L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003101 \text{ g/hr}$$

Air Flowrate 12 l/min of lake B

4) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.6546)(0.0004606 \text{ mg/L}\cdot\text{min})(7.396)(20\text{L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.002676 \text{ g/hr}$$

100mm depth of water sample of lake B (4 l/min)

5) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.7006)(0.0004606 \text{ mg/L}\cdot\text{min})(7.907)(20\text{L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003062 \text{ g/hr}$$

200mm depth of water sample of lake B (4 l/min)

6) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.7080)(0.0004606 \text{ mg/L}\cdot\text{min})(7.986)(20\text{L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003125 \text{ g/hr}$$

300mm depth of water sample of lake B (4 l/min)

7) Slope = 0.0002 mg/L·min

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.6995)(0.0004606 \text{ mg/L}\cdot\text{min})(7.894)(20\text{L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003052 \text{ g/hr}$$

Diference diffuser Arrangement (lake B) – single airstone

8) Slope = 0.0003 mg/L·min

$$K_s = 2.303 \times 0.0003 \text{ mg/L}\cdot\text{min}$$

$$= 0.0006909 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.7126)(0.0006909 \text{ mg/L}\cdot\text{min})(7.870)(20\text{L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.0046497 \text{ g/hr}$$

Diference waste material (cleanwater)

$$\text{Slope} = 0.0003 \text{ mg/L}\cdot\text{min}$$

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0006909 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_s V$$

$$= (0.7128)(0.0006909 \text{ mg/L}\cdot\text{min})(7.874)(20 \text{ L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.0046531 \text{ g/hr}$$

The effect of oxygen transfer under non-steady state conditions

Speed (200rpm) and flowrate (4L/min) – Sample calculation

Refer to the **Table 1.0** and **Table 10** for tabulated data.

To find the value of $\log D_1 - \log D_2$, use the following equation:

$$\log D_{\text{Temperature recorded during the experiment}} - \log D_{T@ \text{At every oxygen reading at interval of 2 minutes}}$$

The average temperature during the experiment is 28.175 °C. At this temperature, from table 10 (appendices c), the saturation concentration C_s (mg/l) by using interpolation. Is :

$$C_{s-28.7} = 7.874 \quad (\text{From Table 10})$$

At 0 minutes, at temperature 28.175 °C:

The oxygen reading : 0.01 (This value represent C_0)

$$\text{To find } D_1, C_s - C_0 = 7.874 - 0.01 = 7.864$$

$$D_1 = 7.864$$

To find D_2 , $C_s - C_{0.15} = 7.874 - 0.01$ (we take C_0) = 7.864

$$D_2 = 7.854 \text{ (then used } C_1, C_2, \text{ etc..)}$$

$$\begin{aligned} \therefore \log D_{1- \text{The first oxygen reading at interval of 2 minutes}} - \log D_2 &= \log 7.864 - \log 7.864 \\ &= 0.896746616 - 0.896746616 \\ &= 0 \end{aligned}$$

When all the value of $\log D_1 - \log D_2$ are calculated, the graph $\log D_1 - \log D_2$ (mg/L) versus time (min) is plotted. A straight line is drawn through the plotted points. The slope of this line is measured. The slope is

$$\frac{\log D_1 - \log D_2}{t^2 - t_1}$$

The value of K_s is calculated by multiplying the value of the slope by 2.303.

From the graph plotted in Figure 1,

$$\text{Slope} = 0.0002 \text{ mg/L}\cdot\text{min}$$

$$K_s = 2.303 \times 0.0002 \text{ mg/L}\cdot\text{min}$$

$$= 0.0004606 \text{ mg/L}\cdot\text{min}$$

$$R = F K_s C_{s(10)} V$$

$$= (0.6977)(0.0004606 \text{ mg/L}\cdot\text{min})(7.874)(20 \text{ L})(60 \text{ min/hr})(1 \text{ g}/1000 \text{ mg})$$

$$= 0.003036 \text{ g/hr}$$

The correction factor, F and saturation concentration C_s , are found by using interpolation from value given in Table 10.

APPENDICES C

TABLE OF CORRECTION FACTOR