DETERMINATION OF OXYGEN DEMAND OF DIFFERENT TYPES OF SEDIMENT FROM THE SAMPADI RIVER

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Determination of Oxygen Demand of Different Types of Sediment from the Sampadi River

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Determination of Oxygen Demand of Different Types of Sediment from Sampadi River

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ABSTRACT
Sediment Oxygen Demand (SOD) is the rate of oxygen consumption by all organisms in the sediment. Numerous cases of water pollution create a potential public health problem as well as threaten the aquatic life. SOD is an important tool to test water quality and it affects the dissolved oxygen (DO) in water resources. The main objective of this study was to determine the SOD of sediment from a river that received shrimp pond effluent, household discharge, and relatively unpolluted sediment. Water and sediment samples were collected from five stations of the Sampadi River for analysis of SOD. Besides, sediment collected and was also analyzed for organic matter, organic carbon, nutrients and particle sizes. SOD ranged from 0.125 to 0.784 g O₂/m²/day for the entire study area. Among the five stations of Sampadi River, S4 showed the second highest SOD mean value of 0.418 g O₂/m²/day. Furthermore, this station also had the highest value for phosphorus, organic matter and organic carbon. The results showed positive correlation between SOD and total phosphorus (mg/kg), nitrogen (%), organic matter (%), organic carbon (%) and particle sizes (%) in bottom sediment of studied stations. S2 showed the highest total Kjeldahl nitrogen percentage of 0.998 % was likely due to the large discharge of shrimp farm effluents since this station is located near to a shrimp farm.

Key words: Sediment oxygen demand, dissolved oxygen, organic matter, nutrient, particle size

ABSTRAK
Permintaan oksigen enapan (SOD) ialah kadar penggunaan oksigen oleh semua organisme dalam enapan. Banyak kes berkaitan dengan pencemaran air telah mengakibatkannya masalah kesihatan di kalangan orang awam dan juga mengancam kehidupan kehidupan aquatik. SOD ialah satu alat untuk menentukan kualiti air dan ia mempengaruhi oksigen terlarut (DO) dalam sumber air. Objektif utama kajian ini ialah untuk mengenalpasti nilai enapan SOD dari Sungai Sampadi yang menerima kumbahan dari kolam udang, pembuangan dari rumah, dan dari enapan yang sedikit tercemar. Sampel air dan sampel enapan diambil dari lima kawasan Sungai Sampadi untuk digunakan dalam analisis SOD. Selain itu, enapan juga dikumpul dan digunakan dalam analisis seperti karbon organik, bahan organik, nutrien dan saiz partikel. Nilai SOD ranged from 0.125 to 0.784 g O₂/m²/hari bagi keseluruhan kawasan kajian. Di antara lima kawasan Sungai Sampadi, S4 menunjukkan nilai purata SOD yang kedua tinggi iaitu 0.418 g O₂/m²/hari. Tambah, kawasan ini juga mempunyai nilai yang paling tinggi untuk fosforus, bahan organik dan karbon organik. Keputusan menunjukkan perhubungan yang positif di antara SOD dengan Total phosphorus (mg/kg), nitrogen (%), bahan organik (%), karbon organik (%) dan saiz partikel dalam enapan pada semua kawasan kajian. S2 mempunyai peratus jumlah Kjeldahl nitrogen yang tertinggi iaitu 0.998 % dan ini dianggapkan ialah kesan daripada kumbahan secara besar-besaran dari kolam udang memandangkan kawasan ini mendekati kolam pemerintah udang.

Kata kunci: Permintaan oksigen enapan, oksigen terlarut, bahan organik, nutrien dan saiz partikel.
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CHAPTER 1
INTRODUCTION

Water pollution has received increasing attention. Water quality is important in maintaining both human health and production of food supplies. However, many factors contributed to water quality deterioration. Human activities are the main factor that contributes to the deterioration of water quality on Earth. Other factors are agriculture, industries, natural processes and household. Huge amount of organic wastes and industrial wastes discharged from agricultural and industrial sources could reduce the dissolved oxygen (DO) available for aquatic life.

Sediment oxygen demand (SOD) is the rate of dissolved oxygen depletion due to all biological and chemical processes in sediments (Doyle and Lynch, 2005). It is reported in unit of g O₂/m².day. The oxygen demand increases as the biological activities in benthic sediment increases and thus lowers the concentrations of oxygen in the overlying waters. Extremely low dissolved oxygen leads to the death of most of the aquatic life as DO is essential for transpiration, respiration, and decomposition processes.

Nitrogen and phosphorus are nutrients essential for growth and reproduction of plants. Large amount of nutrients in the water causes extensive algal growth that may reduce the aesthetic and recreational value of water; causes of aquatic organisms kill due to the depletion of dissolved oxygen when algal blooms die (Tirado and Bedoya, 2008). The process of soil erosion and runoff from land bring soil organic matter into sediments of waterways. The
decayed living things settle at the bottom of the sediment, and used oxygen when microorganisms carry out biological activities.

Water pollution is an environmental issue which affects the whole ecosystem. Therefore, in this study, SOD measurements were made on sediments collected from different locations at the Sampadi River. Sediment oxygen demand determination is important in determining total oxygen demand in aquatic ecosystem. In addition, it can be used to know the nutrient and organic matter fluxes in water ecosystems. Other important parameters of sediment such as organic matter, organic carbon, nutrients and particle sizes were also included in this study. The main objective of this study was to determine SOD of sediment from the Sampadi River that received household discharge, discharge from shrimp farm and unpolluted sediment.
2.1 Dissolved Oxygen (DO)

Dissolved Oxygen (DO) supports all aquatic life in water body; therefore, DO can act as an indicator of water body’s ability to support aquatic life. It is generally considered to be one of the most important parameters of water quality in streams, rivers, and lakes. The amount of oxygen dissolved in water is expressed as a concentration in milligrams per liter (mg/L) of water. It can be determined using standard wet chemistry methods of analysis or by using membrane electrode meters in the laboratory or in the field. The electrode probe senses small electric currents that are proportional to the dissolved oxygen level in the water.

Numerous factors affect DO concentration in a water body. One of the factors is the presence of decaying organic matter in water body. Organic matter in the water usually comes from human activities. When organism decomposes organic matter, they use up oxygen. As a result, the DO level in the water dropped. When the DO level drops until less than 5 mg L⁻¹, it may adversely affect the functioning of biological communities and if it drops to less than 2 mg L⁻¹, it may lead to the death of most fish species (Chapman and Kimstach, 1992).

The other factor is the number of organisms (bacteria and fungi) in the water body. Human activities such as sewage discharge, fertilizer runoff, and leakage from septic systems to water bodies result in the large quantity of organisms in the sediment. Organisms use up oxygen when they decompose organic matter contained in the effluent discharged to sediments.
Again due to human activities, household and fertilizer discharges release nutrients such as nitrate and phosphate to the water bodies causing eutrophication. Nutrients become food for algae. When there is large quantity of nutrients in water, reproduction of algae will also increase. The demand for dissolved oxygen in sediment increases when these algae die as decomposition by bacteria use up oxygen. The effect may be the dissolved oxygen drops to too low a concentration for fish to breathe leading to fish kills.

However, according to Truax et al. (1995), even rivers and estuaries that have not received significant discharges of solids can exhibit significant rates of oxygen uptake, due to benthic ecosystem supported by soluble organic substances in the water column, from naturally occurring sediments derived from aquatic plants and animals, and from detritus discharged into the water body by natural runoff.

Velocity of water flowing in the water body also affects the DO concentration (Murphy, 2008). Turbulence increases the velocity in the water body creating a condition where suspension of sediments occurs resulting in an increased active surface area. Therefore, velocities exposed to sediments must be estimated before the flow rates for the laboratory measurement of SOD can be chosen (Belanger, 1980; Whittemore and Mckeown, 1978a). High velocity in SOD chamber can resuspend bottom sediments. Unwanted resuspension causes turbidity of water inside the chamber to produce incorrect SOD measurement as the biological oxygen demand of the overlying water has been increased (Wood, 2001). Additionally, the oxygen content of natural waters varies with temperature, salinity, photosynthetic activity of algae and plants, and atmospheric pressure.
2.2 Sediment Oxygen Demand (SOD)

Sediment oxygen demand (SOD) is the rate of oxygen consumption due to organisms in the bottom sediments plus any oxygen consumed by purely chemical reactions (Institute of Paper Chemistry, 1978). Sediment oxygen demand is a very important tool used to measure the water quality. Additionally, it becomes an important parameter for dissolved oxygen prediction of water bodies. Water sources such as rivers, lakes and streams have to meet certain water quality goals as required by the Federal Water Pollution Control Act Amendments (PL92-500) (Institute of Paper Chemistry, 1978). The water bodies receiving any discharges will normally have high SOD value compared to unpolluted one.

There are two fundamental approaches to measure SOD: in-situ respirometry and laboratory respirometry. Numerous techniques have been developed for each approach. However, in general, laboratory respirometry techniques have not gained the same credibility as in-situ measurement methods (Whittemore, 1986b). The main difference between in-situ and laboratory methods is the requirement for sample extraction in the laboratory procedure (Truax et al., 1995). The laboratory setup used a sealed, cylindrical chamber through which water is continuously recirculating across the sediment water interface to mimic river condition. A rheostat is installed in each chamber as a function of pump speed controller and as a result leads to the circulation velocity within the chamber.
The SOD rate is calculated by using the following equation:

$$SOD_T = 0.024 \frac{V}{A} (-b)$$  \hspace{1cm} (1)

where $SOD_T$ is the sediment oxygen demand rate in grams of oxygen per square meter per day (g O$_2$/m$^2$/day) at water temperature $T$, $b$ is the slope of dissolved oxygen concentration with time in milligrams per liter per hour (after subtracting the slope measured in the control chamber), $V$ is the volume of the chamber in liters, $A$ is the area of bottom sediment covered by the chamber in square meters, and 0.024 is a units-conversion constant.

The SOD rate at 20 degrees Celsius, $SOD_{20}$, was calculated using Van't Hoff equation:

$$SOD_{20} = \frac{SOD_T}{1.065^{(T-20)}}$$  \hspace{1cm} (2)
where $T$ is the water temperature during measurement in degrees Celcius (Thomann and Mueller, 1987).

Temperature is a primary determinant of the biological and chemical reactions. Biological activity such as decomposition of organic matter consumes the dissolved oxygen available in water column. Thus, when the temperature is high more oxygen in water column will be depleted. The decomposition rate of organic matter in soil often doubles if the temperature is increased from 20°C to 30 °C (Boyd, 1995). So, temperature is considered as factor that affects SOD. However, extremely high temperature will cause the mortality of organisms like microorganism.

Other factor that affects SOD is overlying waters' velocity; an increase in velocity causes an increase in the SOD rate (Whittemore and McKeown, 1978a). In Oregon, Thomas (1970) measured SOD rates at nine sites in the lower Willamette River and found rates as high as 19.5 g/m² d at sites heavily impacted by pollution. Caldwell and Doyle (1995) recently found SOD rates in the same reach of the lower Willamette River to range from 1.3 to 4.1 g/m² d, indicating a substantial improvement in the water quality over 25 years.

2.3 Organic Materials in Sediment

2.3.1 Organic matter

Sediment may contain large amount of organic matter. Sediment organic matter consists of animals or plant material that is in the process of decomposing. The well-decomposed organic matter is called humus (by-product of organic matter decomposition).
2.3.1.1 The Benefit of Organic matter

Organic matter serves as a reservoir for nutrients (Funderburg, 2009). Increasing organic matter in sediment also increases the amounts of nutrients such as phosphorus, nitrogen, sulfur and carbon (Funderburg, 2009). It has good water-holding capacity which acts like a sponge to hold up to 90% of its weight in water (Funderburg, 2009). Besides, erosion prevention by increasing soil organic matter because of water infiltration and stable soil aggregate formation caused by organic matter (Funderburg, 2009). Organic matter is added to soil to improve soil fertility. It is added to the soil in helping nutrients retaining in soil, contributing to plant requirements (Funderburg, 2009). Organic matter in soil can increase the life span of any given soil by preventing weathering forces such as wind and water from destroying it beyond its most productive stage (Funderburg, 2009).

2.3.2 Organic carbon

Organic carbon is carbon-based material from living or dead plants and animals. Organic carbon is a source of energy for living organisms. In cultivation field, a regular practice of restoring organic matter is needed; if not the levels of carbon in the soil would drop, threatening fertility and soil structure (Ecochem, 2008). Soil carbon is important in improving the structure of the soil, which results in better drainage and aeration and better root growth (Rice, 2009). For the microbial community, carbon is an energy source obtaining in greater nutrient cycling and biodiversity (Rice, 2009). In addition, management practices that increase soil carbon also tend to reduce soil erosion, reduce energy inputs and improve soil resources (Rice, 2009). Increasing a soil’s capacity to store carbon will increase crop productivity and enhances soil, water and air quality (Rice, 2009).
2.4 Sediment Particle Size

Soil texture influences the distribution of aquatic organisms that live in soil as soil texture determines capability of soil in nutrient-storage ability, water retention, leaching and erosion potential, ability to hold carbon, organic-matter dynamics. Generally, the finer the sediment, the higher is its capability of water retention and lowers its permeability (Maguire et al., 1997). Also, the fine sediment has the better retention of organic matter and nutrients (Maguire et al., 1997). However, according to Caldwell and Doyle (1995) in their study on SOD in the Lower Willamette River, Oregon in 1994, no statistically significant correlations between measured SOD and the sediment characteristics of sand and organic content were found.

2.5 Nutrients

2.5.1 Phosphorus (P)

Phosphorus (P) is of major significance in plant nutrition which needed to maintain profitable crop production. However, in both terrestrial and aquatic environments it is one of the most limited nutrients (Moss, 1988). Mineral phosphate (PO$_4^{3-}$) fertilizers and animal manures are introduced to agricultural land to increase P levels and maintain crop productivity (Sibbesen and Sharpley, 1997).

Agriculture is now likely to become the main contributors. Even small amount of P loss from the agricultural land can lead to severe impacts on water quality in receiving catchments (Tunney et al., 1997). This plant nutrient enriches the water causing eutrophication in aquatic ecosystems (Tunney et al., 1997). It also increases the biological productivity of surface waters and this is always highlighted by the detection of toxin-producing algal blooms.
(Tunney et al., 1997). Determination of phosphorus in sediment is important to characterize the quality of the water because it contributes to deterioration of water quality (Tunney et al., 1997). Phosphorus is removed from wastewater because it provides a nutrient or food source for algae (Tunney et al., 1997). Dead algae can cause serious oxygen depletion problems in receiving streams which in turn can kill fish and other aquatic life (Tunney et al., 1997). In addition, algae can also cause taste and odor problems in drinking water supplies (Tunney et al., 1997). As a result of these aquatic processes, the cost for drinking water purification increased and the loss of income from recreational tourism (Tunney et al., 1997).

Phosphorus losses from agricultural land are related to the capacity of the soil to retain P (Tunney et al., 1997). This is not related to the initial P source which may include naturally released through the mineralization of organic matter or artificially applied in the form of fertilizers and manures (Tunney et al., 1997). Phosphorus transfer in term of runoff is related to soil particle size fractions, because of the susceptibilities of physical fractions to detachments, erosion and transport. The P content of soil particle often increases with decreasing particle size. For example, sandy soils have a limited P retention capacity (Tunney et al., 1997).

2.5.2 Nitrogen (N)

Nitrogen, N, exists in many forms in the environment and plays important role in environment as it takes part in many biochemical reactions. The four forms of nitrogen are organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen that is significance in environmental technology. Nitrogen is an essential nutrient for plant growth, particularly in
the form of nitrate. Massive amount of nitrogen in surface water promotes unpleasant algae blooms that can degrade water quality and resulting eutrophication problem.

Application of chemical fertilizers in agricultural areas causes the entering of nitrate to groundwater (Tirado and Bedoya, 2008). As a result, groundwater as source of drinking water is contaminated with nitrate (Tirado and Bedoya, 2008). The exceed amount of nitrate in drinking water brings an immediate and serious health treat to infants under 4 months of age (Tirado and Bedoya, 2008). A disease called “blue baby” or methemoglobinemia is caused by nitrate in drinking water (Tirado and Bedoya, 2008). The baby is more susceptible to this kind of disease due to un-well developed enzymes in baby. The nitrate ions react with blood hemoglobin, reducing the blood’s ability to carry oxygen (Tirado and Bedoya, 2008).

2.5.2.1 Nitrogen cycle

Figure 2.2: Nitrogen Cycle (Pidwirny, 2006)
The nitrogen cycle is one of the most important cycles in terrestrial ecosystems (Pidwirny, 2006). Living organisms use nitrogen to produce complex organic molecules like amino acids, proteins and nucleic acids (Pidwirny, 2006). The abundance of nitrogen in the form of $N_2$ is present in the atmosphere; however, most plants can only use nitrogen in two forms, ammonium ion ($\text{NH}_4^+$) and the ion nitrate ($\text{NO}_3^-$) (Pidwirny, 2006). Result from this problem, nitrogen often the limiting nutrient for plant growth (Pidwirny, 2006). The ammonium seldom used by plants because in huge amounts it is toxic (Pidwirny, 2006).

Nitrogen-containing of living or dead organic matters are consumed by animals to obtain nitrogen sources for their metabolism, growth and reproduction needs (Pidwirny, 2006). Decomposers like bacteria and fungi always play an important role that converts the ammonia in organic matter to ammonium salts (NH$_4^+$) (Pidwirny, 2006). This process is known as mineralization (Pidwirny, 2006). Then, ammonia-oxidizing bacteria, Nitrosomonas modify the ammonium to nitrite, NO$_2^-$, further process is nitrite-oxidizing bacteria, nitrobacter, modify the nitrite to nitrate, NO$_3^-$ (Pidwirny, 2006). These processes are called nitrification. On the other hand, denitrification is a process of reduction of nitrate into nitrogen (N$_2$) or nitrous oxide (N$_2$O) gas (Pidwirny, 2006). Both of these gases then go into the atmosphere (Pidwirny, 2006).

### 2.6 Shrimp farming

Shrimp farming is the practice of feeding shrimp in culture pond. It has been expanding in Asia and being the most important exporting commodity of several countries are Thailand, China, Indonesia and India (Ahmed et al., 2002). This kind of practice has created vast job opportunities and substantial income either to local or foreign countries.
However, rapid expansion of intensive shrimp farming without proper planning has created various environmental problems (Anderson, n.d.). Mangrove destruction is one of the factors caused by intensive shrimp farming (Anderson, n.d.). According to Boyd (1992), shrimp effluents always containing high suspended and dissolved organic matter. In addition shrimp pond effluent also containing high load of nutrients, chemicals and antibiotics that are often discharged into receiving waters (Boyd, 1990). The use of excessive feed and fertilizer to produce shrimp can cause eutrophic condition in shrimp aquaculture pond (Boyd, 1985).

Shrimp pond management is important to reduce water contamination. Adequate information about the types of chemicals and antibiotics, their quantities used in shrimp farm and their biological effects should be collected in order to draw conclusion of shrimp farm impacts on environment.
CHAPTER 3
MATERIALS AND METHODS

3.1 Sampling Site

Sampadi River is located in Lundu, Kuching, in the state of Sarawak. In this study, there were five stations of Sampadi River selected to be studied in this study. The five stations are Jeti Kampung Sampadi (S1), Sungai Sebandar (S2), Sungai Langir (S3), Sungai Chupin Besar (S4) and upper stream of Sampadi River (S5). The S1 is a jetty of fishing boats, S2 is a site of shrimp farm discharge, S3 is near to Kampung Maang Lansat which receives household waste, S4 is near to a palm oil factory and receives household discharges from Kampung Limo and S5 is located at the upper stream of Sampadi River which receives discharges from Sungai Pasir and Sungai Teruntum.

Figure 3.1: Sampling Locations of the Sampadi River
3.2 Sample Collection

Water sample was collected in eight gallons of plastic containers with each can be filled with 23 L of water. Water sample was collected at a clean site of the Sampadi River in order to be used in the chambers for SOD determination experiments, while, samples of bottom sediments from each studied station were obtained by using polyvinyl chlorine (PVC) pipes. During the sediment collections, the PVC pipe was driven into the sediment and then removed. The sediment was covered at its top and bottom with PVC covers. Top and bottom sediment were also identified. Three replicates of core samples were collected at each site.

After the cores were sealed it was placed in an icebox and returned to laboratory. The purpose of packing them in ice was to prevent shock and to lower the temperature to reduce bioactivity. The maximum time between coring and arrival at the laboratory was approximately 6 hours. For analysis of TKN, particle size, organic matter, organic carbon and nutrients, the sample of sediments were collected by mixing equal portions of samples from the same location and combining them to become a composite sample. These samples were placed into plastic bags and stored at 4°C until analysis.

3.3 Laboratory SOD Procedures

In this study, laboratory respirometry technique was used for SOD determination. The method is a modification of Truax et al. (1995). This technique involves taking a given amount of sediment, enclosing it in a chamber with a known water volume, and measuring the oxygen uptake with the respect to time. SOD rate can be calculated based on the area of sediment enclosed by the chamber, the volume of water within the chamber, and the rate of
oxygen used up (Whittemore, 1986a). The circulation velocity of SOD chamber was
to create flow rate without any sediment suspension.

Five sediment chambers of five studied stations and one blank chamber were set up at
the same time. All the chambers were filled with samples of channel water. The sample core
tube covers were removed and the cores were put in the chamber. After that, the chamber was
filled with channel water. Pump operation was started and calibrated DO meter was inserted.
Data on DO, time, and temperature were recorded at selected intervals (ten minutes)
dependent on oxygen uptake rate. Sufficient data points were collected to identify the slope of
the oxygen uptake rate using a statistical regression approach, generally 5-10 hours. For this
study, DO concentrations of sediments were recorded for three hours.

Figure 3.2 shows how the sediment chamber was set up. Three sediment core tubes
were enclosed in a chamber filled with water sample. The diameter and height of sediment
core tubes used were 5.08 cm and 12.7 cm. The volume of chamber and surface area of core
used to calculate the SOD rate was 11.34 L and 0.0061m². A DO meter Adwa, AD 61 was
used. DO probe was lowered into the water chamber through the hole made on the top of
chamber cover. The hole of DO probe was sealed with silicon to prevent any air from entering.
The height and inner diameter of chamber were 25 cm and 26 cm respectively. A HAQOS
(SP500) pump was used and the flow rate of pump was about 15 liter per minute. The water
velocity of the water circulation in the container, at the surface of sediment was 14.79 m/s.
The water velocity (deep part) of five studied stations of the Sampadi River ranged from 1.09
to 1.92 m/s. These water velocities were measured by portable flow meter, Flo-Mate (Model
2000).
3.4 Sediment Characterization

3.4.1 Organic Matter

Organic matter was measured according to Loss on Ignition (LOI) method (Boyd, 1995). The Loss on Ignition (LOI) method for the determination of organic matter involved the heated destruction of all organic matter in the soil. A clean crucible was tared and about 2 g of air-dried soil was added. The sample was placed in an oven at 105 °C for 24-48 h. The sample was then removed, cooled in a desiccator, and weighed. The sample was placed in a muffle furnace at 350 °C for 8 h, removed from the furnace, cooled in a desiccator, and reweighed. Compute the organic matter concentration as follows:

\[
OM = 100 - \left( \frac{W_r - W_T}{W_{TS} - W_T} \right) \times 100\%
\]  

(3)