MEASUREMENTS OF SEDIMENT OXYGEN DEMAND (SOD) " *IN-SITU*" MEASURING CHAMBER AND ITS APPLICATIONS FOR STREAM WATER QUALITY MODELING AND AQUACULTURE MANAGEMENT

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ABSTRACT

Sediment oxygen demand is defined as the rate of dissolved oxygen removal from the water column by the decomposition of organic materials in the bottom sediments. Accurate SOD rates are important, as they will allow for more precise permits specifications and therefore the degree or level of wastewater treatment needed. The "in situ" SOD chamber designed for the study was adapted from an earlier design by the USEPA (Hatcher, 1986). The chambers were used to measure the SOD levels in several rivers and streams. The results indicated a wide range of readings with high levels of SOD in river areas with high organic loadings. These measurements were used for the calibration and validation of a wasteload allocation water quality model. Another applied usage of the SOD chamber was for the management of aquaculture ponds. The knowledge of the SOD levels at the bottom of the aquaculture ponds will allow the management to schedule pond cleaning.

Key words: Sediment oxygen demand, SOD chamber, dissolved oxygen, water quality model

INTRODUCTION

The process of calibration and validation of a water quality model needs two major independent variable data other than the measurements of reaeration coefficients and river hydrogeometry. These variables are sediment oxygen demand (SOD) and photosynthesis/respiration. The data for both parameters are minimal or non-existent in Malaysia, therefore field measurements have to be carried out (Mohamed, 2000).

Benthic sediment is recognized as a potentially large oxygen sink in water bodies (Bowman and Delfino, 1980). Past research has indicated that the sediment oxygen demand can account for a major portion of the overall oxygen uptake for some surface waters (Madenjian, 1990).

The SOD rate is an important parameter in water quality modeling especially for modeling dissolved oxygen in surface waters. The predictions from these models are used by government agencies such as the United States Environmental Protection Agency (USEPA) for determining specifications for wastewater discharge permits from municipal and industrial effluent dischargers (Brown and Barnwell, 1987).

The SOD in the water column is determined by the continuous but variable supply of the settling of the organic materials. The organic matter sources include natural leaf and litter fall, death of aquatic organisms, atmospheric deposition, wastewater effluent discharges, and stormwater runoffs. The organic matter from each source differs in both chemical composition and physical characteristics.

The fate of the organic materials from their settled condition in the water column is determined by one of these processes – transportation downstream, decomposition in the water column or settling to the sediments. The processes for different sources would therefore be different due to the different chemical composition and physical characteristics. Larger organic matter would settle out quickly, while smaller particles would be suspended longer in the water column and therefore be transported downstream (Murphy and Hicks, 1986).

The organic matter, which settles from the water column, accumulates on the bottom of the water bodies in irregular patches or islands. The distribution of these oxygen-demanding deposits along the stream bottom is due to the irregular settling pattern of the organic materials. Larger, denser particles settle faster than smaller, lighter particles, and organic matter settles faster in slow, meandering stream areas than in turbulent areas (Hatcher, 1986).

The distance that a suspended matter travels downstream before it is deposited depends upon the velocity of the stream and its depth and upon the particle's settling velocity. The equatic could be written as:

$$x = H * \frac{V}{s}$$
(Equation 1)

where,

x = distance traveled by the suspended particle downstream

H = stream depth

V = stream velocity

s = settling velocity of the particle

Rivers tend to deposit their load of suspended solids in zones of suddenly decreasing velocity such as in the backwaters of reservoirs and in areas of increasing salinity. Increasing salinity flocculates the clay-based particles, which increases the settling velocity of the particles as they increase in size.

Even in a uniform stream, particles of different sizes and densities settle differentially, with the larger, denser materials settling out and the smaller, lighter materials being carried downstream, where they might undergo partial decomposition before they are deposited. This particular settling pattern leads to a non-uniform organic particle deposit, which causes higher SOD rates near the source and gradually decreasing SOD rates further downstream. The longitudinal SOD gradient due to the particles' different settling velocities and SOD variability due to lateral and longitudinal non-uniformity in the stream velocity and the variability of the depth makes it difficult to predict the sediment deposits' locations, depths and their properties.

At the same time, the organic matter deposits can be scoured, resuspended and moved further downstream at higher water velocities (Hatcher, 1986).

Researchers have tried to develop equations for predicting SOD rate, but the search has been frustrating because of the intricacies of many factors affecting SOD.

METHODS OF SOD MEASUREMENT

There is no standard methodology of SOD measurements, but two basic procedures are used by researchers; *in situ* measurements and laboratory analysis. The *in situ* method appears to be the better approach to measuring SOD as it minimizes manipulation of sediment sample and other ambient conditions. However, some studies have indicated that the results are more reproducible in laboratory analysis (Bowman and Delfino, 1980).

Field Measurement Method for Sediment Oxygen Demand (SOD)

The method used for measuring SOD for the study is a modified version of the one used by Murphy and Hicks (Murphy and Hicks, 1989). The method was developed and employed by USEPA, Region IV for the "*in situ*" measurement of SOD. An "*in situ*" SOD measurement involves isolating a known volume of water and area of sediment under an opaque chamber placed on the bottom of a water body. The author used several dimensions and materials but the final version of the SOD chamber used stainless steel with the dimensions stated in Table 1.

Table 1. SOD Chamber Dimensions

Measurement	Unit	Dimension
Diameter	cm	46.00
Height (from flange to top of chamber)	cm	20.00
Cross-sectional area	cm^2	1662.00
Volume	liter	33.24

The dissolved oxygen in the water enclosed within the chamber was read about 15 minutes after its placement on the riverbed. This was to allow for the settling of the disturbed sediment. The purpose of the blank chamber readings, where the bottom of the SOD chamber was sealed and the chamber was filled with the river water on location, was to measure the respiration rate of the water column.

The dissolved oxygen concentration in the chamber is monitored until sufficient time has passed to establish a measurable rate of change in dissolved oxygen concentration. The SOD rate is calculated using the equation:

$$SOD = 1.44 \frac{V}{A}(b_1 - b_2)$$ (Equation 2)

where,

SOD = the sediment oxygen demand $(g/m^2/day)$

b_1	=	the rate of change of dissolved oxygen concentration inside the SOD chamber (mg/L/min)
b_2	=	the rate of change of dissolved oxygen inside a blank chamber (mg/L/min)(water column respiration rate in the chamber)
V	=	the volume of the chamber (liters)
A	=	area of the chamber covering the bottom sediment (m^2)
1.44	=	the constant for converting mg/L/min to $g/m^2/day$.

The blank chamber is a replicate of the SOD chamber, but with the bottom sealed. Therefore, the blank chamber does not measure the SOD demand, but the respiration rate of the contained water. The blank chamber is to be employed simultaneously with the actual SOD chamber (Murphy and Hicks, 1986). In the study, considering the financial constraints, only one chamber was built and the blank chamber used was the SOD chamber with a removable bottom. The "blank" chamber was employed after the SOD measurements were carried out at that particular location.

The values for b_1 and b_2 may be determined from a linear regression analysis, where b_1 and b_2 are the slopes of the curves obtained by plotting the SOD chamber and the blank chamb dissolved oxygen levels versus time, respectively.

The key factors in SOD measurement using the SOD chamber are the chamber volume, chamber surface area, rate of change of dissolved oxygen, and the time elapsed. These factors are important considerations in designing a SOD chamber.

A SOD chamber has to be practical, whereby the chamber should be easily handled and deployed, the trapped air can be purged easily, and the chamber is stable and sealed at high current flows, suitable for use on various river bottom substrates. The SOD chamber also should measure a broad range of SOD rates.

Some technical considerations that must be addressed are volume to surface area ratio, circulation pattern, and over-bottom current velocity within the sealed chamber.

The ratio of volume to surface area is an important initial consideration in chamber design. This factor would dictate several important operational considerations of the SOD chamber such as (1) the total amount of dissolved oxygen available in the chamber, (2) the range of SOD rates capable of being measured, (3) the rate of change of the dissolved oxygen detection capability, (4) the time required to conduct each SOD measurement, and (5) the resuspension effect at the start of the measurement, as the chamber is placed on the substrate (Murphy and Hicks, 1986).

Knowledge about the expected SOD rate ranges to be measured and precision and accuracy of the dissolved oxygen-measuring tool are important for the calculation of the volume to surface area ratio. The chamber volume must be large enough to ensure that sufficient dissolved oxygen is available in the chamber to allow for a measurement to be carried out. Too small of a volume, a high SOD from the substrate and the resuspension during the placement of the chamber would deplete the dissolved oxygen before a sufficient number of observations.

The method of dissolved oxygen measurement within the chamber is to preferably use an electronic probe coupled to a dissolved oxygen meter as it allows the chamber dissolved oxygen to be continuously read without the need to extract water samples, which by itself would create water bubbles within the chamber. A well-maintained and calibrated dissolved oxygen probe and dissolved oxygen meter can be used to monitor dissolved oxygen concentrations as low as 0.05 mg/L every 10 or 15 minutes' interval with precision and accuracy. In the study, Yellow Springs

Instruments YSI Model 58 Dissolved Oxygen meter was used with the oxygen probe of model YSI 5739 with a 100 feet cable (Yellow Springs Instruments, Yellow Springs, Ohio).

Several important operational considerations can be examined due to volume to surface area ratio of a SOD chamber. Minimizing the volume to surface area ratio, for a given SOD rate, increases the rate of change of the dissolved oxygen in the chamber. Therefore, the accuracy within of the dissolved oxygen readings is enhanced because of the larger changes occurring within the shorter time period. Increasing the volume to surface area ratio expectedly has the opposite effect and would cause dissolved oxygen rate of change to be too small to be detected within an acceptable time limit. One disadvantage of decreasing the volume to surface area ratio of the SOD chamber is that it would decrease the total dissolved oxygen in the chamber. Excessive resuspension during the placement of the chamber would cause a rapid decrease in the dissolved oxygen content of the chamber. This condition, plus a high SOD rate of the substrate could deplete the total dissolved oxygen within the chamber before a good SOD rate can be measured.

Mixing of the water within the enclosed chamber is also critical as the mixing allows for uniform dissolved oxygen concentrations throughout the chamber. Self-stirring dissolved oxygen probes are not adequate for the purpose as the attached stirrer circulates too little volume to effectively mix the whole chamber. Diffusers or immersible pumps such as the ones used for aquarium circulation purposes could fulfill the need but must be placed and oriented to achieve complete mixing within the chamber, providing reasonably uniform over-bottom velocities and at the same time the velocity is not fast enough to cause excessive disturbance and resuspension of the bottom sediments which can cause erroneous readings. The submersible bilge pump used to circulate water in the SOD chamber for the study was Model 24 from Rule® 500 (Rule Industries Inc., Gloucester, Ma.) obtained from Grainger Incorporated. The capacity of the pump is 360 gph (lph). The positioning of the bilge pump and the circulation tubes near the top of the chamber was as such as to prevent excessive resuspension of the bottom sediment that would cause erroneous readings.

Ideally, over-bottom velocity in the SOD chamber should emulate the ambient velocity of the stream being tested, but such a condition is difficult to achieve. Therefore, a fixed mixing rate with a constant over-bottom velocity low enough to avoid excessive resuspension is recommended. The usage of a smaller capacity in the second set of SOD chambers was to avoid possible excessive resuspension of the sediment.

The SOD chamber must be designed with a flange and a cutting edge. A vertical cutting edge and a horizontal flange stabilize and seal the chamber to the sediment surface. In soft and muddy sediment the flange limits the chamber intrusion into the sediment thus ensuring a known chamber volume.

Another important consideration that has to be examined is the prevention and detection of chamber leakage, as an effective chamber to substrate seal is essential to prevent ambient water from leaking into the chamber and altering the chamber dissolved oxygen concentration. The integrity of the chamber seal can be tested by injecting a concentrated salt solution such potassium chloride (KCl) or sodium chloride (NaCl) at the beginning of the experiment and monitoring the electrical conductivity within the chamber to detect declining values after stabilization of readings, which indicates a leak of ambient waters into the chamber. The method is applicable only in freshwater as the conductivity of brackish and salt water is too high for the method to be used. A Salinity-Conductivity-Temperature (SCT) meter Model 33 (Yellow Springs Instruments, Yellow Springs, Ohio) was used for leakage detection from the SOD chamber in the study.

RESULTS OF FIELD MEASUREMENTS OF SEDIMENT OXYGEN DEMAND (SOD)

Sediment oxygen demand (SOD) rates were measured using the SOD chamber at Alor Lempah (Sg. Selangor proper) and at Sg. Kerling, which is a tributary of Sg. Selangor. The chamber was also employed for a SOD study of the upper reaches of Sg. Skudai in Johor and the recreational lake in Universiti Teknologi Malaysia (UTM), Skudai (Figure 1). The results of the study up to the present time is shown in Table 2.
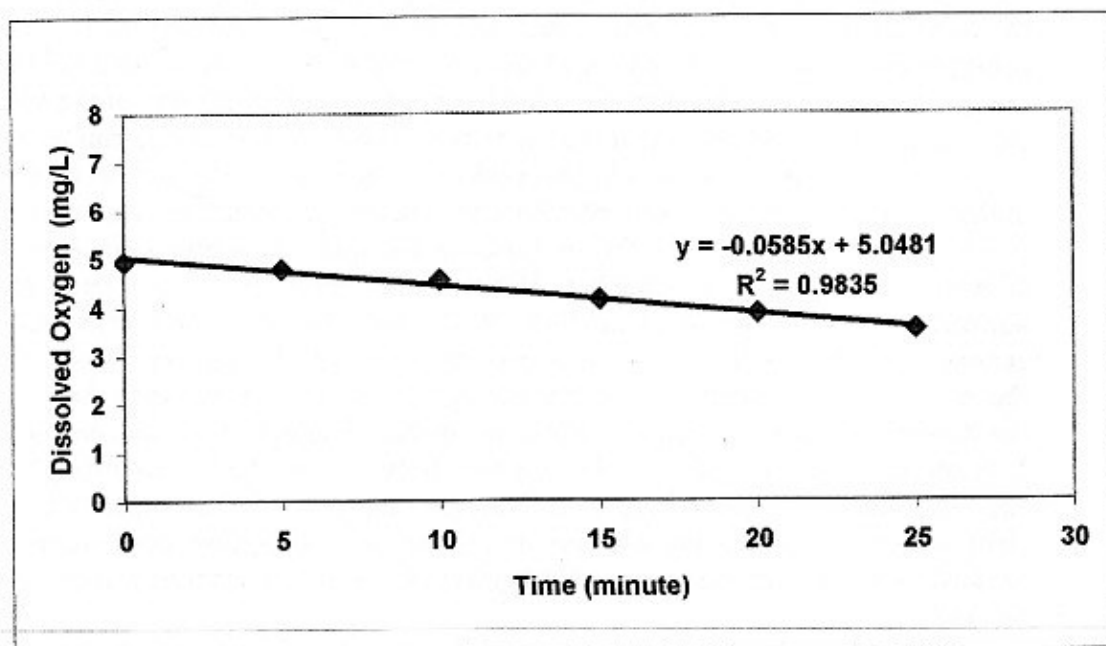

Figure 1. SOD Measurement at Site 1 (UTM Recreational Lake)

Table 2. SOD study results in several rivers and a lake in Malaysia

River	n	SOD $(g/m^2/day)$	Average SOD $(g/m^2/day)$	Remarks
Sg. Selangor at Alor Lempah	2	3.78 3.54	3.66	Sandy substrate mixed with leaf litter
Sg. Kerling at Kerling	2	0.41 0.25	0.33	Sandy substrate
Sg. Skudai at Sedenak	2	2.24 0.73	1.49	Fine sand/silt mix with organic layer underneath
Sg. Skudai at Sengkang	2	1.45 1.76	1.61	Fine sand
Sg. Melana (Sg. Skudai tributary) at Taman Pulai Utama	5	0.87 2.89 4.35 2.89 2.57	2.71	Fine silt
Universiti Teknologi Malaysia Recreational Lake	4	4.25 0.44 1.43 1.32	1.86	Fine organic sediment (organic)

The chamber was later used for the study of pollution prevention and river rehabilitation of Sg. Tebrau in Johor. An example of the measurement results is shown in Table 3.

Table 3: Sediment Oxygen Demand for Sungai Tebrau

Location	SOD $(g/m^2/day)$
Senai 1	0.144
Senai 2	1.987
Kg. Maju Jaya	0.720
Pasar Borong Pandan	2.074

Adjustment were made to standardize the SOD rates to a common temperature using the formula:

$$SOD_T = SOD_{20}\theta^{(T-20)} \qquad \text{(Equation 3)}$$

where,

SOD_T	=	SOD rate at temperature T ($^\circ$C)
k_{20}	=	SOD rate at reference temperature of 20 $^\circ$C
θ	=	temperature correction factor (dimensionless)

The temperature correction factor used is 1.065.

Table 2 also indicated large differences between SOD readings at the same site. This phenomenon occurred for both Sg. Skudai at Sedenak and UTM Recreational Lake. The most plausible explanation is the uneven settling of the benthic sediment.

Butts and Evans (1978) suggested SOD levels ranges as related to the pollution levels of the sediment as indicated in Table 4.

Table 4. Levels of SOD related to sediment quality (Butts and Evans, 1978)

Range of SOD at 25 $^\circ$ C $(g/m^2/day)$	Quality of Benthic Sediment
< 0.5	Clean
0.5 – 1.0	Moderately clean
1.0 – 2.0	A little polluted
2.0 – 3.0	Moderately polluted
3.0 – 5.0	Polluted
5.0 – 10.0	Very polluted
> 10.0	Possibly sewage sludge

DISCUSSION AND CONCLUSIONS

The unsteady stream hydraulics and variable organic particle loading rates of most natural streams cause spatial and temporal variability in the distribution of the sediment deposits and the sediment oxygen demand. Therefore, it is most difficult to accurately characterize a stream's SOD distribution by using SOD measurements taken at only a few locations at only limited time periods. In this case then it is necessary for the researcher or the water quality modeler to carry out more SOD readings for each particular site to ensure that the average value calculated can be used for the calibration and validation of the water quality model used.

Aquaculture management research also indicated that a pond's bottom is not homogenous with respect to SOD (Berthelson et al., 1996). Certain portions of the pond bottom were found to be hard and compact while other portions had layers of soft sediment overlaying hard sediment. Generally, sections covered with a soft layer had a higher SOD. Anyway, the trend of the aquaculture industry toward ever increasing fish or shrimp production rates has changed management strategies such as feeding and aeration rates. Additional nutrient loading and the subsequent biochemical activity may have a profound effect on the SOD. Therefore, continuous monitoring of the ponds for SOD levels would be necessary.

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