

Oxygen-Transfer Measurement in Clean Water

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Abstract

This paper presents the experiments on measurement of oxygen transfer capacity in clean water by using desorption and absorption techniques. Experiments were set up in a small-scale tank with a volume of 17L. Pure oxygen was used to increase the dissolved oxygen concentration in clean water (desorption measurement). While sodium sulfite was added to decrease the dissolved oxygen concentration in absorption measurement. Standard oxygen transfer coefficient ($K_L a_{20}$) was calculated based on the variation of dissolved oxygen concentration with time. For the absorption method, a mean value of $K_L a_{20}$ can be obtained as 8.60 h^{-1} with a water volume of 14L. Meanwhile, standard oxygen transfer efficiency (SOTE) was shown in the range of 4.5-4.9% with water depth 0.3m by correcting the airflow condition. Desorption measurement was investigated to certify the influence of water depth on SOTE. All the data on dissolved oxygen concentration and tested water temperature was read by an electronic DO meter.

Keywords : dissolved oxygen concentration, oxygen transfer coefficient ($K_L a_{20}$), standard oxygen transfer efficiency (SOTE), absorption measurement, desorption measurement and water depth.

1. Introduction

The oxygen transfer capacity and the aeration efficiency characterize the performance and economy of aeration installations in activated sludge plants [1]. From 1978, the guideline for the determination of the oxygen transfer capacity has been published. In 1984, the American Society of Civil Engineers (ASCE), with international participation, published the ASCE Standard "Measurement of Oxygen Transfer in Clean Water". The test water shall be equivalent in quality to a potable public water supply. Repetitive testing may be conducted in the same water, provided that the TDS is not over 2000 mg/L [2].

This article presents the methods of measurement based on the second edition of ASCE Standard and German ATV Standard, and verifies the influence of measurement condition. A diffuser was adopted to convey the oxygen into a batch tank. Absorption and desorption measurements were used to determine the oxygen transfer coefficient and oxygen transfer efficiency. All the results were analyzed based on standard condition, which is defined as water temperature of 20°C and normal atmospheric pressure (1013 hPa). A DO meter is the main instrument to measure the dissolved oxygen concentration, which can be used to calculate the transfer rate. Finally, the paper concludes the characteristic of the diffuser by SOTE. Meanwhile, various influence factors will be analyzed by the data treatment.

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2. Theory

2.1 Definitions

2.1.1 Oxygen Transfer Coefficient ($K_L a_T$, h^{-1})

$K_L a_T$ is determined by evaluation of an oxygen transfer test in clean water at a certain aeration setting and at a certain temperature. It is converted to the standard temperature of $T=20\text{ }^{\circ}\text{C}$ as follows:

$$K_L a_{20} = K_L a_T * 1.024^{(20-T)} \quad (1)$$

2.1.2 Standard Oxygen Transfer Rate (SOTR₂₀, $\text{kg-O}_2\text{h}^{-1}$)

SOTR shows the amount of oxygen transferred per hour at the standard condition. It can be calculated by the following:

$$\text{SOTR} = K_L a_{20} * C_{s,20} * V \quad (2)$$

where $C_{s,20}$ is the steady-state DO saturation concentration at 20°C and V is the liquid volume.

2.1.3 Standard Oxygen Transfer Efficiency (SOTE, %)

SOTE refers to the fraction of oxygen in an input airflow dissolved under the standard condition. It can be computed by:

$$\text{SOTE} = \text{SOTR} / W_{O_2} \quad (3)$$

where W_{O_2} (kg/s) is the mass flow of oxygen in air stream, which is calculated by:

$$W_{O_2} = 0.2765 Q_s \quad (4)$$

Q_s refers to air flow rate at standard condition defined as $0\text{ }^{\circ}\text{C}$, 1.00 atm , and dry air (0% relative humidity) [1]. Therefore, data about humidity, pressure and temperature are necessary for the conversion of the airflow rate.

2.2 Summary of Test Methods

2.2.1 Absorption Measurements

The oxygen transfer is determined from the increase of the previously, artificially lowered DO concentration [1]. 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 increases according to the saturation function:

$$C_t = C_s - (C_s - C_0) * \exp(-K_L a_T * t) \quad (6)$$

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 .

2.2.2 Desorption Measurements

The oxygen transfer is determined from the decrease of the previously increased DO concentration. Pure oxygen should be used to improve the DO concentration. Hydrogen peroxide can be an alternative of pure oxygen in most cases. An increase of DO of about 10 mg/L should be achieved before the measurement. The decrease of the DO follows a reversed saturation function, which equals to the one in absorption measurements.

2.3 Correction Factors

Due to the difference between the test condition and the standard condition, the data from the

measurement should be converted into standard condition by some correction factors.

$$C_{s,20} = C_{s,T} \left(\frac{1}{\tau \Omega} \right) \quad (7)$$

τ is the temperature correction factor equal to $C_{sT,T} / C_{sT,20}$ where $C_{sT,T}$ and $C_{sT,20}$ are the tabular value of DO surface saturation concentration at test temperature and 20°C, standard total pressure of 1.00 atm and 100% relative humidity. Ω is the pressure correction factor, which can be described as P_b / P_s where P_b and P_s are the barometric pressure at test site during test and at standard state (1 atm). In this experiment, an assumption was made that Ω is 1.

3. Experimental Process

3.1 Set-up

The equipment includes a 17 L of cylindrical tank with a diameter of 24 cm., a DO meter (YSI model 550), a cylindrical ceramic diffuser, airflow meter and aerating device (Figure 1). The DO probe was installed at half water depth for absorption measurement. If more DO probes are applied, they can be installed at different water depth. Conductivity meter was used to measure the content of dissolved solids.

3.2 Operation Process

Both absorption measurement and desorption measurement were applied in the experiment. The difference between two methods can be explained

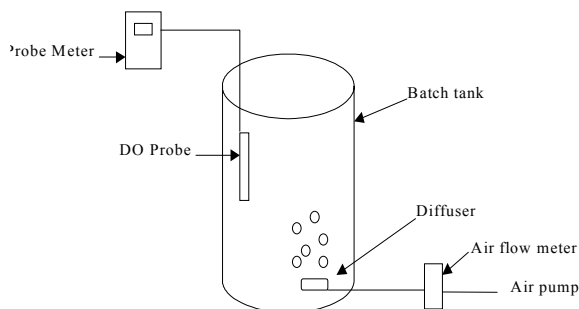


Figure 1 Sketch for experiment set-up

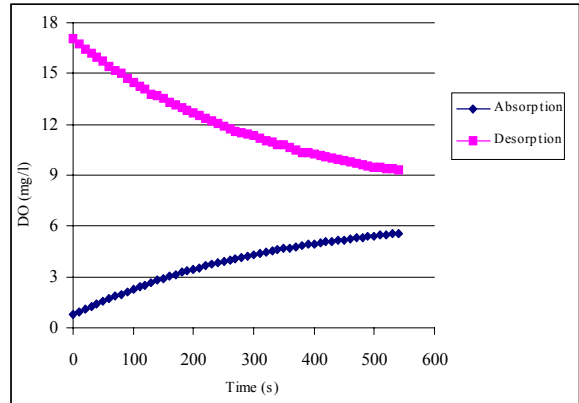


Figure 2 DO variation in different processes

by the Figure 2. The variation of DO concentration is completed by either pure oxygen injection or chemical addition.

3.2.1 Calibration of DO Probe

Calibration of DO probe is necessary for the precise measurement. The methods used in this experiment consist of zero check and saturation check. The zero check is run every time after the probe is turned on, by putting probe into a 1-L tube added by 1 g sodium sulphite and 1 mg cobalt. With excess chemical, the water in the tube should contain zero dissolved oxygen. Saturation check can be done before and after measurement, according to the operation manual for the probe [3].

3.2.2 Temperature Measurement

The temperature of test water can be read from the DO meter. The variation of temperature shall be with an accuracy of $\pm 0.5^\circ\text{C}$ at the beginning and the end of each test [1].

3.2.3 Airflow Rate Measurement

A laboratory flowmeter made by G.A. Platon Ltd is used to measure the airflow rate. The accuracy of the flowmeter has been checked before application. The inverse measuring cylinder filled with water was used to calibrate air flowrate. The airflow of $1550 \text{ cm}^3/\text{min}$ was applied in the measurement.

3.2.4 Water quality

TDS (Total Dissolved Solid) and conductivity of the test water were measured by a conductivity meter, when each test was finished. If TDS shows a value higher than 2000 mg/L, the test water (clean water) shall be changed.

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

3.2.6 Desorption Measurements

Pure oxygen and air tubes were connected to a three-way valve fitting the other end to the diffuser. Pure oxygen was fed from an oxygen cylinder by a pressure-regulator valve through the diffuser into the clean water. When the DO concentration was increased to about 17 mg/L, the regulator was shut off and the air pump was switched on.

3.2.7 Data Collection

With absorption method, when the concentration of oxygen increases from zero, the test data can start at about $C = 0.1 C_{s,T}$. The end point of the test

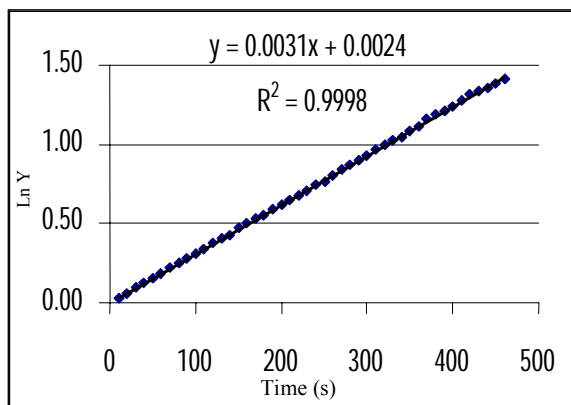


Figure 3 Plot of LnY versus time

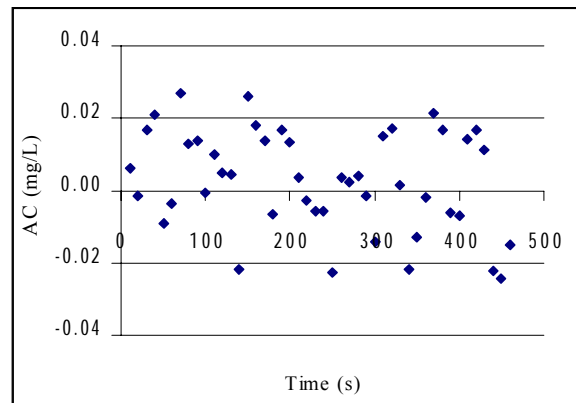


Figure 4 Plot of residues of DO from a test
 AC: Difference between the measured DO and the predicted DO

should not exceed $0.8 C_{s,T}$. At least 30 values should be collected for the data analysis. Desorption method demands a start point that is 10 mg/L higher than the saturation value.

4. Data Treatment

Linear regression method is used to analyze the data from the experiment. This method is based on the model through the DO-versus-time data. However, equation (5) gives a nonlinear relationship between DO concentration and time. Transformation of this equation is necessary before it is applied. A linear relationship can be obtained by equation (8).

$$\ln\left(\frac{C_s - C_t}{C_s - C_0}\right) = K_L a_T * t \quad (8)$$

See in Figure 3, the slope of the plot between $\ln Y = \ln\left(\frac{C_s - C_t}{C_s - C_0}\right)$ and time giving a value of is 0.0031 s^{-1} . The best estimates of the parameters, $K_L a_T$, is selected as the values that drive the model equation through the prepared DO concentration-versus-time data points with a minimum residual sum of squares [2]. The residual refers to the difference in concentrations between a measured DO value at a given time and the DO value predicted by the model at the same time (Figure 4).

If the residue shows a curve, normally the initial values of DO concentration are falsified by the lagging sodium sulphite oxidation or unstable mixing conditions. Incorrect values at the end of the curve could influence the curved path of residues. So, a new calculation is necessary, leaving out several initial values or several final values [1].

5. Result and Discussion

5.1 Determination of $K_L a_{20}$ in Clean Water

Absorption method is adopted to measure the oxygen transfer rate in clean water. Results have been converted into the standard condition by a temperature correction factor shown in equation (1). Figure 5 shows the results from the water sample with a depth of 0.30m. One thing should be noticed that the following results are not trying to explain the relationship between temperature and $K_L a_{20}$ or SOTE. Theoretically, values of $K_L a_{20}$ should be same due to the temperature correction.

The values of $K_L a_{20}$ are between 8.3 and 9 h^{-1} in the range of tested water temperature of 27.6-29°C. The mean $K_L a_{20}$ is 8.60 h^{-1} . Temperature, water depth, and airflow could be the influence factors.

The results of SOTE values are within the range of 4.52-4.81% as shown in Figure 6. The values are much smaller than the reference numbers because of the low water depth. Water turbulence may affect the probe readings. Accurate probe

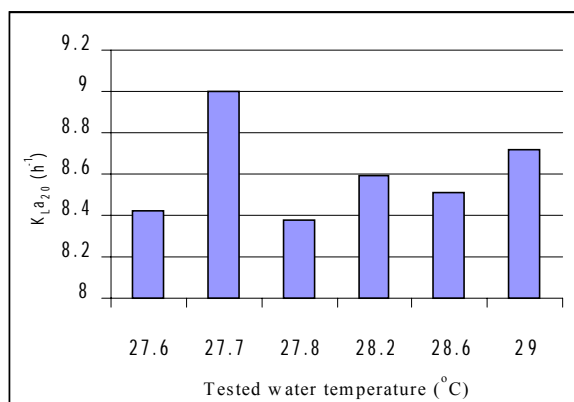


Figure 5 Results of transfer rate in clean water by absorption measurement

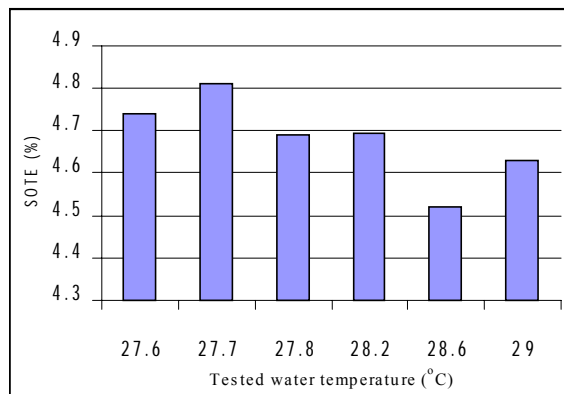


Figure 6 Results of SOTE in clean water

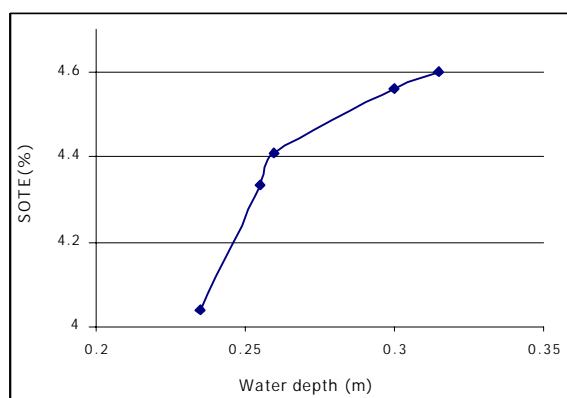


Figure 7 Effect of water depth on SOTE

readings generally require a liquid velocity of at least 0.3 m/sec near the water interface [2]. In this experiment, we avoid stagnation by rapidly moving the probe through the sample [3].

5.2 Influence of Water Depth

Desorption technique was used to verify the influence of water depth in the clean water. Five different water depths (0.24, 0.26, 0.27, 0.30, and 0.32m) are chosen as test objective.

Since the diffuser is installed at the bottom of the tank, water depth can indicate the diffuser depth. Figure 7 shows that SOTE increases with the water depth because the contact time increases between the bubble and the water. The increase of oxygen partial pressure could be another reason for SOTE's increasing [5]. However, this relationship

only gives a tendency of variation of SOTE values, instead of the precise values. Due to the small interval of water depths chosen in this experiment, it is impossible to measure the exact change of SOTE with water depth. For a precise measurement of SOTE variation with water depth, a larger interval (0.5 m or more) between water depths should be chosen.

5.3 Comparison of Absorption and Desorption Measurement

Figure 7 gives a SOTE value of 4.56% at water depth 0.3m by desorption measurement, which is within the range of 4.52-4.81% (Figure 6) at the same water depth from absorption measurement. Both methods can meet the requirement for clean water measurement. With addition of chemicals in absorption measurement, TDS shall be controlled under 2000 mg/L; while no consideration of TDS is necessary with desorption measurement. The economic factor shall be taken into consideration when choosing a method. The comparison of cost between pure oxygen and chemicals added can be investigated further.

6. Conclusion

The practice of absorption and desorption methods for measurement of oxygen transfer coefficient in the laboratory, have been presented in this paper. The test condition should be controlled

strictly, such as temperature, airflow rate and stir of water. The precision of experiment can be improved by applying more DO probes at the different test points.

7. Acknowledgement

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