Specific Oxygen Uptake Rate and Mass Transfer Coefficient in Activated Sludge System

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Abstract: Activated sludge process is one of the effective methods in biological wastewater treatment and the impact of oxygen transfer through aeration process has the most important breakthroughs as it served as the largest consumer in the treatment. Aeration is an energy demanding process. Oxygen transfer into an activated sludge is a very challenging issue in the field of multiphase flows. Apart from the physical mass transfer phenomena between gas, liquid and solids phases, the transport mechanisms are also overlapped by time and temperature, varying microbial activity, impurity loads, adsorption and desorption processes. Oxygen uptake rate (OUR) for microbial population in the activated sludge system is important parameter to determine the amount of oxygen consumed during aerobic heterotropic biodegradation in the system. Evaluation of specific oxygen uptake rate (SOUR) and the volumetric mass transfer coefficient (K_LA) of oxygen for three different wastewater treatment processes, namely conventional activated sludge (CAS), oxidation ditch (OD) and sequencing batch reactor (SBR) treating municipal wastewater in Kuala Lumpur have been carried out. In-situ and ex-situ measurement of pH, dissolved oxygen (DO), temperature, MLSS and MLVSS were carried out. In the activated sludge treatment, very low concentration of dissolved oxygen may cause the wastewater to turn septic resulting in death of bacteria or in active due to unstable anaerobic conditions. Conversely, an excessive dissolved oxygen may result to high energy and high operating cost. Higher flowrate may also cause dissolved oxygen to rise, reducing the quality of sludge and slowing the denitrification process in the system. Results revealed that the OUR for SBR, OD and CAS were 9.582 mg O_2/L/hr, 10.074 mg O_2/L/hr and 13.764 mg O_2/L/hr, respectively. Low oxygen uptake rate indicates a low rate of microbial respiration. By computing the OUR, the mass transfer coefficient could be evaluated. It should be noted that among the treatment system in this study, the conventional activated sludge shows the highest mass transfer coefficient and specific oxygen uptake rate of 2.038 hr^{-1} and 15.605 mg O_2/g MLVSS/hr, respectively. Improving the oxygen transfer rate and reducing aeration in the system could achieve a cost-effective aeration system.

Keyword: Activated sludge process, Microorganisms, Oxygen uptake rate (OUR), Volumetric mass transfer coefficient (K_La)

1. Introduction

Wastewater treatment using scientific and engineering methods has been improving remarkably over the years, due to the increased demand and reduced supply for clean water. Wastewater can be defined as polluted water generated by human activities which consists a high amount of toxic chemicals, organic and inorganic contaminants and pathogenic microorganisms (Riffat, 2013). Wastewater could be treated by supplying oxygen. This is because microorganisms consume oxygen to degrade wastewater contaminants. By measuring dissolved oxygen, the oxygen uptake rate can be evaluated by plotting the slope of dissolved oxygen against time. Since microorganisms in activated sludge require oxygen to consume organic matter, a high oxygen uptake rate indicates a high microbial activity and organic matter content, and vice versa. Dissolved oxygen should be provided in adequate amounts, from 1 to 3 mg/L (Spellman, 2009). An insufficient amount of dissolved oxygen will cause the bacteria to die due to the unsuitable anaerobic conditions, causing the process to become septic. In addition, other than the decrease of active microorganisms, there will be the formation of filamentous bacteria, which brings a negative impact to the sludge settleability (Wilén, Markiewicz and Nilsson, 2010). However, too much dissolved oxygen will not be economically friendly due to the wastage of energy and money.

In aerobic treatment, oxygen is supplied throughout the reactor by using diffusers or aerators because microorganisms present in the water require oxygen to break down of organic matter, such as phosphorus and nitrogen, as part of the treatment process. The transfer of oxygen to liquid from gas phase is the main technique used in order to maintain the desired dissolved oxygen concentration. In wastewater, the amount of oxygen is limited by the low solubility of oxygen in water and the rate of mass transfer. Thus, enhancing the oxygen transfer will be able to maintain the desired level of oxygen concentration as well as improving the efficiency of the treatment system. Oxygen uptake rate (OUR) is the microorganism respiration rate per unit time. The OUR is proportional to the microorganism concentration and depends on the quality of the incoming wastewater. In a normal activated sludge, the value of OUR is approximately 30 mg/L.hr. For an extended aeration process, the value of OUR is approximately 10 mg/L.hr (Riffat, 2013). Thus, this parameter is very suitable for monitoring and control of the activated sludge system. It can be utilized as an approach to discover the hazardous matter which can potentially pose a negative impact to the performance of wastewater treatment process (Kim et. al., 2001).

Oxygen uptake rate (OUR) is used to estimate the rate for the microorganisms to consume oxygen to degrade organic matter. Oxygen uptake rate divided by the amount of volatile suspended solids would yield specific oxygen uptake rate (SOUR). Specific oxygen uptake rate and mass transfer coefficient are calculated as below:

$$\text{SOUR}, \left(\frac{\text{mg}}{\text{g.hr}}\right) = \frac{\left(\text{OUR}, \ \frac{\text{mg}}{\text{L.min}}\right)\left(60\frac{\text{min}}{\text{hr}}\right)\left(1000\frac{\text{mg}}{\text{g}}\right)}{\text{MLVSS}, \frac{\text{mg}}{\text{L}}} \qquad \text{Eq (1)}$$

where,

SOUR = Specific oxygen uptake rate, mg O_2/g.MLVSS/hr

OUR = Oxygen uptake rate, mg O_2/L/hr

MLVSS = Mixed liquor volatile suspended solids, mg/L

$$K_L a\left(C^*_{O_2} - C_{O_2}\right) - q_{O_2} x = 0 \quad \text{Eq (2)}$$

where,

$k_L a$ = Volumetric mass transfer coefficient, 1/hr

$C^*_{O_2}$ = Saturation concentration of oxygen, mg/L

C_{O_2} = Concentration of oxygen, mg/L

q_{O_2} = Specific oxygen consumption rate, mg O_2/g cell/hr

x = Concentration of biomass, g cell/ L

$q_{o2}.x$ = Oxygen uptake rate (OUR), mg O_2/L/hr

The objective of this study is to determine the specific oxygen uptake rate (SOUR) and evaluate the mass transfer coefficient (K_LA) of oxygen transfer for different types of activated sludge treatment, namely conventional activated sludge, oxidation ditch and sequencing batch reactor.

2. Materials and methods

2.1 Sampling

All activated sludge samples were collected at the aeration tank of three different municipal wastewater treatment plants that are using different treatment system namely activated sludge, oxidation ditch and sequencing batch reactor in Kuala Lumpur.

2.2 Analysis

All parameters for in-situ and ex-situ measurements such as pH, temperature, dissolved oxygen, mixed liquor suspended solids and volatile suspended solids were analysed according to APHA methods.

2.3 Oxygen uptake rate measurement

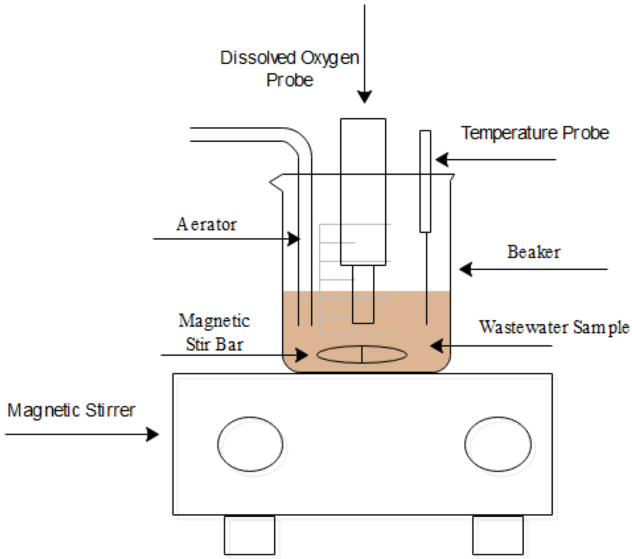

Figure 1. Schematic diagram for oxygen uptake rate measurement.

Oxygen uptake rate was evaluated by obtaining the slope from the reduction of dissolved oxygen against time. The sludge sample was filled in a 1-litre beaker containing a magnetic stir bar and placed on a magnetic stirrer. The beaker was filled with the sample and tightlysealed with parafilm tape to prevent contact with the surrounding atmosphere. In the beaker, air tubing that was connected to the air pump and inserted into the beaker to aerate the sample to desired dissolved oxygen concentrations. A temperature probe was also inserted into the beaker to observe the change of temperature with respect to time. When the sample was aerated, the air pump was switched on to supply oxygen. Once the DO concentration reached 5.0 mg/L, the air pump was switched off and the magnetic stirrer was switched on. The experimental setup for oxygen uptake rate is shown in the **Figure 1.** Dissolved oxygen was recorded from 1 min to 15 min and all samples were tested in triplicate.

3. Result and discussion

Measuring the specific oxygen uptake rate in the treatment system will indirectly measure the organic load at the inlet including the existence of harmful matter that could potentially harm the treatment system. Three different municipal wastewater treatment namely conventional activated sludge (CAS), oxidation ditch (OD) and sequencing batch reactor (SBR) have been sampled and analyzed.

Table 1 shows the data of SOUR and K_LA in this study and the comparison with the range of the designed treatment system. In-situ analysis includes pH, DO and temperature were recorded at site. Results showed that the wastewater for all three locations are acidic, with pH reading of lower than 7.0. It was observed that sequencing batch reactor treatment system has the lowest pH value of 5.82. Lower pH might due to the growth of filamentous bacteria in the system.

Results also revealed that the SOUR for CAS, OD and SBR were 15.5, 4.9 and 3.2 mg/g.hr, respectively. CAS yields the highest value reflecting that higher rate of microorganism respiration were needed in the treatment system. In this treatment system, the production of excess sludge is minimized by oxidation and extended retention time. However, it should be noted that the oxygen uptake rate is highly dependent on microbial activity.

Table 1. Operating conditions for different types of municipal treatment system.

	Unit	Conventional activated sludge (CAS)	Oxidation ditch (OD)	Sequencing batch reactor (SBR)
pH		6.57	6.61	5.82
Temperature	°C	29.4	29.3	28.6
DO	mg/L	0.8	0.8	0.7
OUR	mg/O_2.L	13.764	10.074	9.528
K_LA	hr^{-1}	2.083	1.522	1.407
MLSS	mg/L	1238	2746	4128
MLVSS	mg/L	882	2028	2926
SOUR	mg/g.hr	15.506	4.967	3.275

Table 2. Optimum range for specific oxygen uptake rate in this study and for different treatment plants (Geraldi 2002).

Process Modification	SOUR Range	In this study
Conventional	8-20 mg/h/g VSS	15.506 (CAS)
Extended Aeration	3-12 mg/h/g VSS	4.967 (OD) 3.275 (SBR)

Table 2 shows the optimum range for specific oxygen uptake rate for different treatment plants. It should be noted that in this study, the SOUR values for all treatment system falls within the optimum range. Hence, the rate of degradation in each of the treatment system was enough.

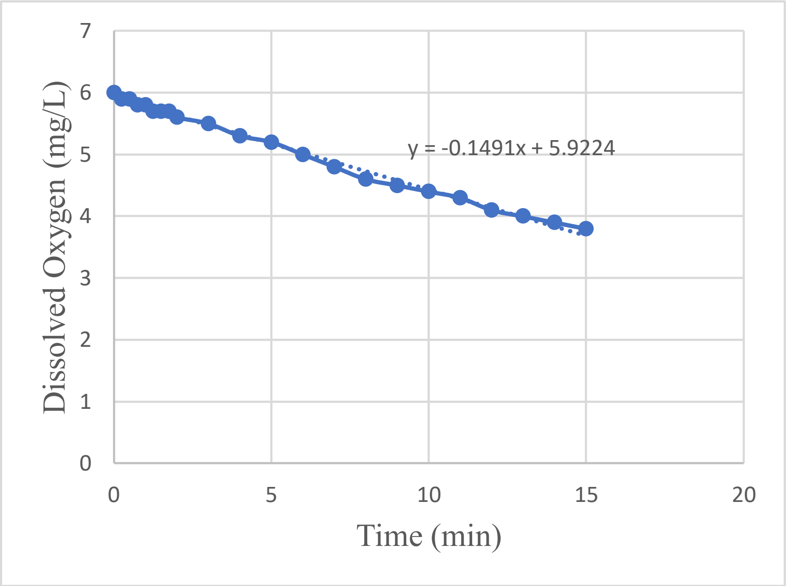

Figure 2. Dissolved oxygen over time for sample collected from sequencing batch reactor.

The OUR reflects on the quantity of oxygen which is used by microorganisms. This is done by observing the reduction of DO against time. **Figure 2** shows the trend of dissolved oxygen collected from sequencing batch reactor which is the lowest among the treatment system. Some of the main factors resulting to reduction of dissolved oxygen are the increase in microbial activity, a higher organic loading, or a low MLSS or MLVSS. Lower temperature and higher MLSS or MLVSS concentration will also affecting the concentration of dissolved oxygen in water.

4. Conclusion

The evaluation of specific oxygen uptake rate and the volumetric mass transfer coefficient of oxygen for three different wastewater treatment processes, namely conventional activated sludge, oxidation ditch and sequencing batch reactor treating municipal wastewater in Kuala Lumpur have been carried out. In-situ and ex-situ measurement of pH, dissolved oxygen, temperature, MLSS and MLVSS were carried out. Results revealed that the OUR for SBR, OD and CAS were 9.582 mg O_2/L/hr, 10.074 mg O_2/L/hr and 13.764 mg O_2/L/hr, respectively. Low oxygen uptake rate indicates a low rate of microbial respiration. The conventional activated sludge shows the highest mass transfer coefficient and specific oxygen uptake rate of 2.038 hr^{-1} and 15.605 mg O_2/g MLVSS/hr, respectively. However, the value is within the acceptable range for the treatment system. Improving the oxygen transfer rate and reducing aeration in the system could achieve a cost-effective aeration system.

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