The Study of Micro-Pressure Inner-Loop Bioreactor Oxygen Mass Transfer Characteristics

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Abstract. The oxygen mass transfer characteristics in a Micro-Pressure Inner-Loop bioreactor (MPR) were studied by clean water oxygenation experiment, the results show that when the aeration adopt by 0.1, 0.2, 0.4, 0.6 m³·h⁻¹, respectively, the oxygen mass transfer coefficient \(K_{La(20)}\) in the reactor increases with the increase of the aeration. \(K_{La(20)}\) shows a good linear correlation with the aeration. The rate is \(0.2128 \text{ h}^{-1} \text{m}^{-3} \text{min}^{-1}\) and the correlation coefficient \(R=0.993\). However, the trend of \(E_{O2}\) increases first and then decreases with the increase of aeration. When the aeration increased to 0.4 m³·h⁻¹, the \(E_{O2}\) reaches the maximum. If aeration increases constantly, \(E_{O2}\) begin to decrease excessive aeration may lead to an increase in energy waste during reactor operation.

1. Introduction
Micro-Pressure Inner-Loop bioreactor (MPR) is a new type of sewage disposal plant, which uses underwater microporous aeration device as oxygen filling and circulating power system making the mixture within the reactor to form the loop flow. The combination of anaerobic zone, anoxic zone and aerobic zone is realized in the same reactor, and the pollutants such as organic matter, nitrogen and phosphorus in the wastewater are removed simultaneously. Compare with conventional concentric circles (or ellipse) runway type loop sewage treatment process such as Orbal oxidation ditch process, OCO process, AOR process, MPR has advantages of a smaller footprint, simple equipment, and lower energy consumption [1].

Aeration oxygen is the most energy-consuming in the wastewater aerobic biological treatment process of link [2-3]. The mass transfer performance of oxygen is directly related to the effect of aerobic oxidation and the energy consumption of wastewater treatment [4]. Based on this, the oxygen mass transfer characteristics in a Micro-Pressure Inner-Loop bioreactor were studied by clean water oxygenation test, the effect of aeration on the oxygen transfer coefficient \(K_{La}\) and oxygen transfer efficiency \(E_{O2}\) was explored in order to obtain the optimum aerobic oxygen supply parameters of the process, which provided the theoretical basis for the subsequent amplification and future practical application of the process.

2. Materials and Methods
2.1. Experiment Setup

The experimental device as shown in Figure 1, the MPR made of organic glass, the reactor is divided into two parts, the upper part of the structure size: 80 mm × 100 mm × 100 mm, main effect is to raise the water level, make the next part of the reaction zone under micro pressure; give priority to the reaction zone, a portion of the effective volume 48 L, structure size: 800 mm × 100 mm × 600 mm, and the main reaction zone set guide plate in place to facilitate fluid circulation flow is formed within the reactor. The main reaction zone from exposing to the side at the bottom of the installation perforation revealed the trachea. Aeration aperture is 1.2 mm. The water in the water tank is pumped into the reactor by the metering pump. Reactor intermittent cycled operates. Through the determination of dissolved oxygen instrument the dissolved oxygen (OXI 3310 SET1, WTW) in the reactor in the process of test.

![Figure 1. Schematic diagram of experimental set up](image)

2.2. Experiment Method

At first we will put 54 L tap water in the reactor. Dissolved oxygen instrument is used to test the concentration of dissolved oxygen. We can calculate the content of dissolved oxygen in water. The theoretical amount of Na$_2$SO$_3$ is calculated according to the principle reaction. The actual amount of oxygen added agent is 120% of the calculated value. At the same time we add 0.25 g catalysts to the reactor (Put the chemicals into reactor before dissolving). Please open the reactor internal mixture stirring pump for 10 minutes. Making the dissolved oxygen concentration in water is close to zero. Put dissolved oxygen probe inside the reactor. Start aeration. The dissolved oxygen values of the detection sites were recorded at intervals of 1 min.

Oxygen transfer efficiency $E_{O_2}$:

$$E_{O_2} = \frac{VK_{La}(C_s-C_t)}{q\rho_{O_2} \times 21\%}$$

(2)

where $V$ is volume of reactor, m$^3$; $q$ is aeration intensity, m$^3$·min$^{-1}$; $\rho_{O_2}$ is density of oxygen in air (1.429 g·L$^{-1}$).

As the temperature of each time during the experiment is different, it is necessary to require the temperature correction $K_{La(T)}$. $K_{La(T)}$ when the experiment temperature $T$ is unified into $K_{La(20)}$ at 20°C:

$$K_{La(20)} = \frac{K_{La(T)}}{1.02^{1.0T-20}}$$

(3)
The effects of different conditions on the oxygen transfer characteristics were evaluated by the characteristic parameters \( K_{La(20)} \) and \( E_{O2} \).

### 3. Results and discussion

#### 3.1. The relationship of \( K_{La(20)} \) and aeration
Control the aeration by adjusting the gas flow meter. Aeration is 0.1, 0.2, 0.4, 0.6 m\(^3\)·h\(^{-1}\) which is under the condition of reactor \( E_{O2} \). The results are shown in Figure 2. From Figure 2, the oxygen mass transfer coefficient \( K_{La(20)} \) in the reactor increases with the increase of the aeration. Analyzing the reasons as: first, when aeration is smaller, bubble is less and density is lower in the reactor, the rising rate of bubbles is slower and the flow of the liquid in the reactor mixed degree is weaker, so the total mass transfer coefficient of oxygen is not high; second, when aeration is larger, density is higher in the reactor and gas is relatively liquid disturbance degree increased, the liquid turbulent degree is enhancing. Thereby, the gaseous oxygen bubbles can promote through a gas liquid double membrane into the liquid becoming dissolved oxygen. The total mass transfer coefficient of oxygen is rising [5]. After correlation analysis found: \( K_{La(20)} \) shows a good linear correlation with the aeration. The rate is \( 0.2128 \; \text{h} \cdot \text{m}^{-3} \cdot \text{min}^{-1} \) and the correlation coefficient \( R=0.993 \). In general, bubble merge phenomenon is more serious with aeration increasing synthesis of gas-liquid constant surface area than after the big bubbles. The oxygen mass transfer will weaken. \( K_{La(20)} \) in reactor increased rate slowing down as the increase of aeration. But the increasing rate of \( K_{La(20)} \) in the reactor is almost constant. This is because aeration has bigger influence on the internal circulation flow reactor. Increase the air-gas liquid turbulence intensity increases by offsetting the oxygen mass transfer from the negative influence.

![Figure 2. Aeration and \( K_{La(20)} \) correlation analysis](image)

#### 3.2. Oxygen transfer efficiency and the aeration
To control aeration by adjusting the gas flow meter. Aeration is 0.1, 0.2, 0.4, 0.6 m\(^3\)·h\(^{-1}\) which is studied under the condition of reactor \( E_{O2} \). The results are shown in Figure 3. From Figure 3: the \( E_{O2} \) in the reactor increases first and then decreases with the increase of aeration, when aeration increases to 0.4 m\(^3\)·h\(^{-1}\), \( E_{O2} \) reaches the maximum. If aeration increases constantly, \( E_{O2} \) begin to decrease. Analyzing the reasons as: when the aeration increases to a certain degree, the oxygen mass transfer effect to achieve a better condition, if aeration increases constantly, and the oxygen mass transfer effect increases unobvious. But the oxygen system is greatly increased. Thereby, result in oxygen transfer efficiency decreased, and the amount of aeration is bigger, more serious waste of energy.
Figure 3. The influence of aeration on $K_{La(20)}$ and $E_{O2}$

4. Conclusions

The conclusions are as follows:

1. The $K_{La(20)}$ in the Micro-Pressure Inner-Loop bioreactor increases with the increase of the aeration. $K_{La(20)}$ shows a good linear correlation with the aeration. The rate is $0.2128 \text{ h} \cdot \text{m}^3 \cdot \text{min}^{-1}$ and the correlation coefficient $R=0.993$.

2. The $E_{O2}$ in the Micro-Pressure Inner-loop bioreactor increases first and then decreases with the increase of aeration. Oxygen mass transfer effect to be a better state while the aeration increased to a certain extent. If aeration increases constantly, the oxygen mass transfer effect increases unobvious. But the oxygen system is greatly increased. Thereby, result in oxygen transfer efficiency decreased, and the amount of aeration is bigger, more serious waste of energy.

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