Advances in Biological Sciences Research, volume 3
International Conference on Biological Engineering and Pharmacy (BEP 2016)

A Comparison of the Oxygen Release from Roots of Thalia and Pontederia in Constructed Wetland Wastewater Treatment Systems

Chan DONG
College of Applied Chemistry
Nanjing Polytechnic Institute
College of Water Conservancy and Hydropower Engineering
Hohai University
Nanjing, P.R.China
e-mail: chan_dong@163.com

Yinghao HUANG
Geotechnical Engineering Department
Nanjing Hydraulic Research Institute
Nanjing, P.R.China
e-mail: ythuangyinghao@163.com

Abstract—**To investigate the ability of oxygen release from roots of different vegetation, and explain the mechanism. This paper tested the variation of oxygen release rate from roots of Thalia and Pontederia using a titanium (Ш) citrate buffer. The results shows that oxygen release rates with the same condition were higher for Thalia. This difference is caused by the special structure of Thalia. The aerenchyma of Thalia is good at the oxygen transport. The results of this paper can help us to choose better vegetation species for wastewater treatment.**

Keywords-constructed wetland; vegetation; oxygen release

I. Introduction

Constructed wetlands (CWs) are artificial wetlands which are designed and constructed to manipulate the natural processes to treat wastewater[1]. Macrophytes play several roles in engineered ecosystems helping to stabilize the surface of the beds, provide good conditions for physical filtration and insulate the surface against coldness[2-4]. Organic matter production and plant uptake of nutrients as well as root-zone oxygen and organic carbon release were identified as key factors influencing nutrient transformation and sequestration in low-loaded systems[3-5]. A recent innovation in horizontal sub-surface flow CWs has been the inclusion of forced aeration to promote aerobic conditions and ammonia removal[6-8]. This has proved successful in the US[9] and testing is producing successful results in the UK[10] and Europe[11]. However, little was known about the ability of oxygen release from roots with different species. And the reason of the difference is still unclear. This paper aims to test the ability of oxygen release from roots of different vegetation, and explain the mechanism. It can help us to optimize the operation of wetland systems.

II. Materials and Methods

A. Experimental Materials and Procedures

Young *Thalia dealbata* and *Pontederia cordata* were collected from a natural wetland located in Xuanwu Lake, Nanjing. After collection, the plants were transplanted to individual plastic pots filled with respective nutrient solutions (self-made nutrient solutions with average concentrations of COD and TN of 50mg/L and 15mg/L, respectively) for three weeks before sowing. The plants were removed from the pots and their roots were gently washed free of debris twelve hours before experiments. The plants (*Thalia dealbata*) had 20-80 adventitious roots which varied in length from 15-64cm and were up to 0.121±0.013cm (n=96) in diameter. Their height of above-ground was 65-80cm. And the plants (*Pontederia cordata*) had 34-95 adventitious roots which varied in length from 12-38cm and were up to 0.108±0.036cm (n=126) in diameter. Their height of above-ground was 52-75cm.

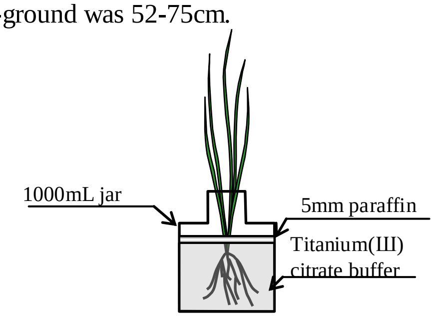

Figure 1. Schematic sketch of the root oxygen release rate detecting device.

Oxygen release from the roots was examined using a non-phytotoxic titanium (Ш) citrate buffer, which allows root oxygen release measurements in a reducing, oxygen-scavenging solution with a low redox potential[12,13]. The 1000mL jar was initially filled with 900mL distilled water, and the water was then sparged with N_2 gas for 60 min to remove any oxygen dissolved in the water. Sparging with N_2 gas was continued while titanium (Ш) citrate stock solution (made by 0.2249g citric acid and 8mL $TiCl_3$) were added. The basal part of the shoot was wrapped with tinfoil to prevent the oil from infiltrating the aerenchyma. The stirring from the sparging was necessary for complete mixing. The roots of plants were submerged in the solution. A 5mm thick layer of paraffin oil was placed on top of the solution to prevent re-aeration from the atmosphere. It ensured that the roots were the only possible source of oxygen entry into the chamber. The root chamber was shielded from light using a tight-fitting tinfoil cover. Blank jars without plants were also prepared in similar way to serve as negative control. Figure.

1 shows the experimental device used in the investigation of the root oxygen release rate. The experimental device was exposed to the open air and natural light in a sealed area outside the laboratory building. Light intensity was measured every 1 hour using a luminometer (MODEL ZDS-10F-2D). The unit of light intensity is lux. Details of the experimental set-up are shown in table I.

TABLE I. LIGHT INTENSITY, TEMPERATURE AND HUMIDITY DURING EXPERIMENTS

Experimental date	PAR [μmol·m^{-2} s^{-1}]		Temperature [℃]		Humidity [%]	
	Average	range	Average	range	Average	range
4 September	319.6	0-1316.9	28	24-35	49	24-60
2 October	391.5	0-1141.4	24	17-33	41	12-59
3 October	370.9	0-1068.9	23	18-32	39	12-57

Sample number is 24. PAR is photosynthetically active radiation. One lux is 0.019 μmol·m-2 s-1[14].

B. Sampling and Analytical Methods

Since the oxygen released from the roots was oxidized by Ti^{3+} in titanium (Ш) citrate buffer, rates of root oxygen release could be calculated from the rate of decrease in the concentration of Ti^{3+} in the jars. As the brown titanium (Ш) citrate solution gradually became clear during oxidation, the samples were taken every 1 hour using a small syringe and the absorbance at 527nm was measured immediately using a spectrophotometer. The absorbances of the samples were compared to those of solutions with a known concentration of Ti^{3+}. At the same time, the light intensity, temperature and humidity were examined. The relation of Ti^{3+} and O_2 is described in the Eq. (1). It is seen that 1mol O_2 is consumed when 4mol Ti^{3+} were reduced. The oxygen consumption (ΔO_2, mg) is thus calculated using Eq. (2). Thereafter, the root oxygen release rate (V_O, μmolg^{-1}h^{-1}) could be calculated using Eq. (3).

$$O_2 + 4Ti^{3+} + 4H^+ = 4Ti^{4+} + 2H_2O \tag{1}$$

$$\Delta O_2 = \frac{32 \times V \times (C_0 - C_e)}{4 \times 47.73} \tag{2}$$

Where V is the volume of titanium (Ш) citrate buffer, 0.9L. C_0, C_e are the initial and end Ti^{3+} concentration, respectively.

$$V_O = \frac{\Delta O_2 \times 1000}{24 \times 32 \times Root\ dry\ weighs} \tag{3}$$

III. RESULTS AND DISCUSSION

Values for root oxygen release were obtained from Ti^{3+} concentrations measured in the test jars, via the above equations. Diurnal fluctuations in oxygen release and PAR are shown in Figure 2 and 3. Our results reveal a significant difference in rate of root oxygen release between day and night. Oxygen release increased gradually with increasing light intensity during the morning. A decrease in oxygen release occurred during the decreasing light intensity of the afternoon. At night, oxygen release rate approached 0 μmolg^{-1}h^{-1}. In all three experiments, the start and end times of oxygen release were closely related to light. The maximum oxygen release rate (256.5–325.7 μmolg^{-1}h^{-1} and 154.6–285.6 μmolg^{-1}h^{-1} for *Thalia* and *Pontederia* respectively) was observed during the daytime at 15:00 hrs, while the maximum light intensity was observed at 13:00 hrs. The maximum value of PAR ranged from 1068.9 to 1316.9 mmolm^{-2}s^{-1}. Clearly, the peak of root oxygen release occurred after the peak of light intensity.

We show that rate of oxygen release depends largely on light intensity and exhibits a diurnal periodicity. Variations in oxygen release and light intensity follow unimodal patterns during the daytime and can be accurately described by the Gaussian function.

We can use of light intensity data in prediction of the quantity of oxygen likely to be released using Gaussian function[15], which is in the form of follows:

$$V_O = ae^{-\frac{(t-t_{Omax})^2}{c^2}} \tag{4}$$

Where t is time (4:00am~20:00pm); a (in Gaussian function) is the maximum value of oxygen release rate in a whole day; t_{Omax} is the location of the symmetry axis in Gaussian function; c expresses the gradient of Gaussian function. Decrease in c is relative to steep Gaussian function while increase in c is relative to gentle Gaussian function.

Light intensity data during daytime (4:00am-20:00pm) also follow Gaussian function, it can be described as:

$$PAR = be^{-\frac{(t-t_{Lmax})^2}{d^2}} \tag{5}$$

Where PAR is the photosynthetically active radiation, μmol·m^{-2} s^{-1}; t is time; b is the peak value of PAR in a whole day; and d is the gradient of unimodal.

For *Thalia* system, the relationship between parameters a and b, c and d are as follows:

$$a = 29.65e^{0.00166b} \qquad c = 8.24e^{-0.3518d} \tag{6}$$

The parameters for *Pontederia* are as follows:

$$a = 24.22e^{0.0018b} \qquad c = 2.3184e^{0.1719d} \tag{7}$$

Modeling parameters obtained are shown in Table II. Then, the root oxygen release rate was predicted and jointly illustrated in Fig. 4. The results reveal that our model data closely match our experimental values. The oxygen release rate increased exponentially with increased *PAR*. And the oxygen release rates with the same condition were higher for *Thalia*. Because its parameter "*a*", which means the maximum value of oxygen release rates in one day-night, was higher. This difference is caused by the special structure of *Thalia*. Oxygen is produced through photosynthesis, and oxygen transport from the sections of the plant above the ground through the rhizome into the fine roots is effected by specific areas of tissue formed in the plant known as the aerenchyma. The aerenchyma of *Thalia* is good at the oxygen transport.

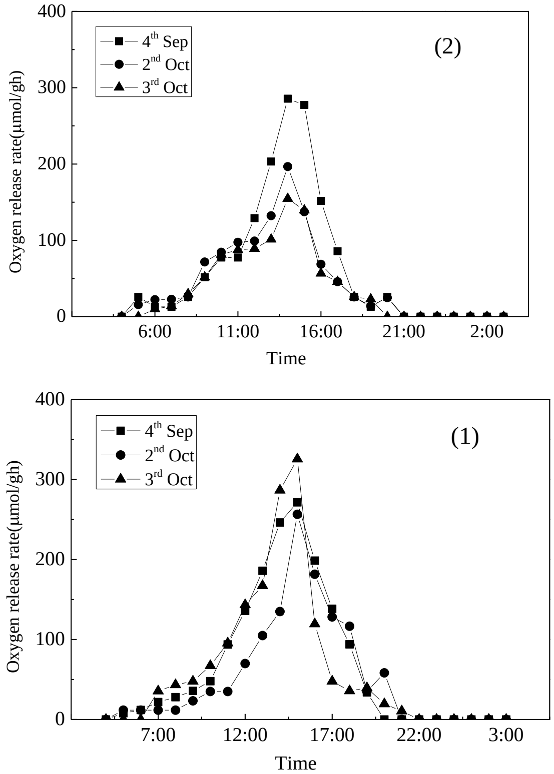

Figure 2. Diurnal fluctuation of oxygen release from the roots of Thalia (1) and Pontederia (2).

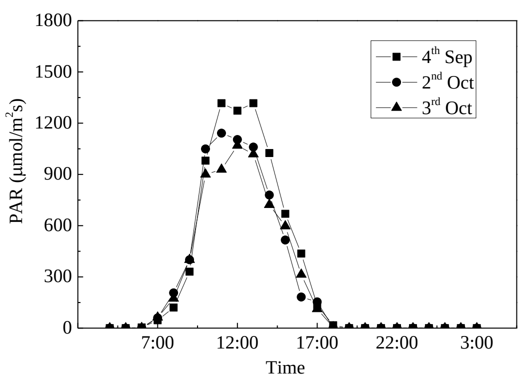

Figure 3. Daily changes of photosynthetically active radiation.

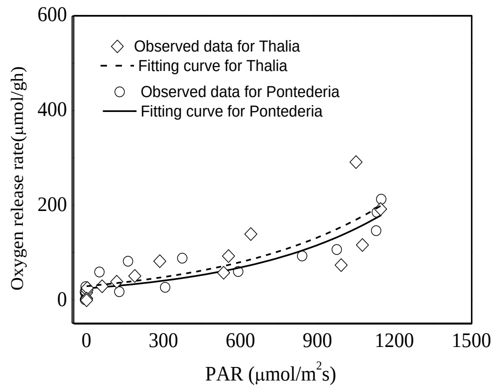

Figure 4. The effect of light intensity on root oxygen release rate.

TABLE II. THE PARAMETERS OF MODELING

Date	PAR		Oxygen release by Thalia		Oxygen release by Pontederia	
	b (μmol·m^{-2} s^{-1})	d	a (μmolg^{-1}h^{-1}	c	a (μmolg^{-1}h^{-1}	c
4st September	1214	3.137	251.6	3.361	215.4	3.975
2nd October	1214	3.137	201	3.212	215.4	3.975
3rd October	1092	3.33	278.9	2.598	172.9	4.110

IV. CONCLUSIONS

The results reveal that oxygen release rates with the same condition were higher for *Thalia*. Firstly, oxygen release rate increased exponentially with increased *PAR* in both of the two systems. However, the rates of oxygen released from roots were higher for *Thalia* than *Pontederia* all the time. And than the parameter “*a*” for *Thalia* was higher. This difference is caused by the special structure of *Thalia*. The aerenchyma of *Thalia* is good at the oxygen transport. The results of this paper can help us to choose better vegetation species for wastewater treatment.

ACKNOWLEDGEMENTS

This work was financially supported by the National Natural Science Foundation of China (51308184), humanities and Social Science Projects of Nan Jing College of Chemical Technology (NJCC-2014-YB-05), the Natural Science Foundation of Jiang'su University (16KJB610017), Jiangsu province environmental protection scientific research subject (2016058), research project of Nanjing Polytechnic Institute (NHKY-2015-03), and Jiangsu Students’ Project for Innovation and Entrepreneurship Training (201512920006Y).

REFERENCES

[1] J. Chen, X.D. Wei, Y.Sh. Liu, G.G. Ying, Sh.Sh. Liu, L.Y. He, H.Ch. Su, L.X. Hu, F.R. Chen, Y.Q. Yang, Removal of antibiotics and antibiotic resistance genes from domestic sewage by constructed wetlands: Optimization of wetland substrates and hydraulic loading, *Sci. Total Environ.* **565**, 240-248 (2016).

[2] T. Carballeira, I. Ruiz, M. Soto, Effect of plants and surface loading rate on the treatment efficiency of shallow subsurface constructed wetlands, *Ecol. Eng.* **90**, 203-214 (2016).

[3] H. Brix, Do macrophytes play a role in constructed treatment wetlands? *Water Sci. Technol.* **35**, 11-17 (1997).

[4] J. Vymazal, Plants used in constructed wetlands with horizontal subsurface flow: a review, *Hydrobiologia* **674**, 133-156 (2011).

[5] C. Tanner, Plants as ecosystem engineers in subsurface-flow treatment wetlands, *Water Sci. Technol.* **44**, 9-17 (2001).

[6] E. Butterworth, A. Richards, M. Jones, H. Brix, G. Dotro, B. Jefferson, Impact of aeration on macrophyte establishment in sub-surface constructed wetlands used for tertiary treatment of sewage, *Ecol. Eng.* **91**, 65-73 (2016).

[7] C. Ouellet-Plamondon, F. Chazarenc, Y. Comeau, J. Brisson, Artificial aeration to increase pollutant removal efficiency of constructed wetlands in cold climate, *Ecol. Eng.* **27**, 258-264 (2006).

[8] L. Zhang, Y. Liu, Y. Shen, H. Liu, Y. Xiong, Effect of limited artificial aeration on constructed wetland treatment of domestic wastewater, *Desalination* **250**, 915-920 (2010).

[9] R. Kadlec, S. Wallace, Treatment Wetlands, second ed. Taylor & Francis Group, FL, USA (2009).

[10] E. Butterworth, G. Dotro, M. Jones, A. Richard, P. Onunkwo, Y. Narroway, B. Jefferson, Effect of artificial aeration on tertiary nitrification in a full-scale subsurface horizontal flow constructed wetland, *Ecol. Eng.* **54**, 236-244 (2013).

[11] J. Nevala, Effect of Design on Treatment Performance, Plant Nutrition and Clogging in Subsurface Flow Treatment Wetlands, Aarhus University, Aarhus (Ph.D. Thesis, 2012).

[12] B.K. Sorrell, W. Armstrong, On the difficulties of measuring oxygen release by root systems of wetland plants, *Journal of Ecology*, **82**, 177-183 (1994).

[13] N. Dorthe, K. Jespersen, Sorrell, Brian, Brix, Hans, Growth and root oxygen release by Typha latifolia and its effects on sediment methanogenesis, *Aquatic Botany* **61**, 165-180 (1998).

[14] X.Q. Mei, Z. H. Ye, M. H. Wong, The relationship of root porosity and radial oxygen loss on arsenic tolerance and uptake in rice grains and straw, *Environ. Pollut.* **157**, 2550-2557 (2009).

[15] C. Dong, W. Zhu, M. Gao, L. F. Zhao, J. Y. Huang, Y. Q. Zhao. Diurnal Fluctuations in Oxygen Release from Roots of Acorus calamus Linn in a Modeled Constructed Wetland, *J. Environ. Sci. Health., Part A* **46**, 224-229 (2011).