EFFECT OF DRY-WET ALTERNATION ON DISSOLVED OXYGEN CONCENTRATION IN CONSTRUCTED WETLAND

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Abstract. The effect mechanism of dry-wet alternation on dissolved oxygen (DO) concentration in constructed wetlands have not been fully studied. In this paper, the experimental device of constructed wetland in constant temperature box is taken as the research object, and the effect is analyzed at different temperature systematically, changes of DO concentration with different substrates and effects of different dry-wet ratios on DO concentration. The results showed that the dissolved oxygen (DO) concentration increased with the decrease of temperature at different dry-wet alternation times (DAWT) 4 h, 8 h and 12 h. At various temperatures (10°C, 20°C, 30°C), the DO concentration decreased with the increase of DAWT. At the same dry-wet alternation time, DO concentration in each substrate increased with the higher dry-wet ratios. At the same time, it was found that the concentration of DO in the Biochar substrate was lower than that in the Common substrate (Macadam, Zeolite, volcanic rock). Therefore, the dry-wet alternation can increase the dissolved oxygen content of constructed wetland significantly, that is, reducing the dry-wet alternation time (speeding up the frequency) and increasing the dry-wet time ratio are beneficial to the recovery of the reoxygenation ability in constructed wetland.
Keywords: *dry-wet ratio, biochar, substrate, dissolved oxygen, reoxygenation*

Introduction

Dissolved oxygen (DO) concentration is the key factor affecting the purification effect of Constructed Wetland. The results show that the denitrification mechanism of wetland is mainly microbial nitrification, denitrification and anaerobic ammonia oxidation (Huang et al., 2014; Jiang et al., 2019). The amount of nitrogen removal by nitrification and denitrification can account for 60%~86% of the total amount of nitrogen removal (Liu et al., 2003; Faulwetter et al., 2009; Jiang et al., 2019), and the main reason is that wetlands create a good nitrification and denitrification environment for microorganisms. However, the concentration of dissolved oxygen in the wetland is low because of the limitation of Wetland structure, which greatly limits the purification capacity of the wetland, resulting in the unsatisfactory decontamination effect of the wetland (Van-Ostrom et al., 1994; Wu et al., 2001).

Generally speaking, there are great differences in the requirements for the dissolved oxygen content in the process of microbial denitrification in constructed wetland, because

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nitrification is an aerobic process, denitrification and anaerobic ammonia oxidation are anaerobic processes, and all single oxygen environment is easy to cause the process of biological denitrification in wetland is not smooth. We know that the oxygen suitable for nitrification should be higher than 2 mg/L, otherwise DO will be the limiting factor of the reaction, and 0.2 mg/l is considered as the minimum do requirement for nitrification; in addition, DO of denitrification should be controlled below 0.5 mg/l, and denitrification above this value will be severely inhibited. Therefore, some new design processes that can improve the reoxygenation capacity of wetland have emerged, such as artificial aeration method (Li et al., 2001; Yan et al., 2007), tidal flow artificial wetland (Sun et al., 2005), wave type subsurface flow artificial wetland system design (He et al., 2004), indirect design water way design (Song et al., 2005; Wu et al., 2010; Zhang et al., 2015), pre aeration (Noorvee et al., 2007), ventilation pipe (Green et al., 1998; Lahav et al., 2001; Ouellet-Plamondon et al., 2006), blast aeration (Yan et al., 2007; Nivala et al., 2007), etc. Some results show that these reoxygenation measures can effectively improve the nitrification capacity of wetland, but the continuous oxygen increase will lead to a large increase in the concentration of nitrate nitrogen in the effluent of wetland, thus reducing the removal efficiency of total nitrogen (Jamieson et al., 2003). So, how to dynamically control and optimize the distribution of oxygen state in the wetland and promote the nitrification and denitrification is very important for the denitrification and decontamination effect of the wetland.

Alternation of drying and wetting is the most basic feature of wetland ecosystem. The alternation of soil / sediment / substrate water is closely related to the enrichment and removal of nutrients. Under the operation mode of dry and wet regulation, the change state of dry and wet alternation (water level fluctuation, anaerobic / aerobic environment alternation, etc.) can also occur in the constructed wetland. However, the mechanism of the effect of dry and wet alternation on the dissolved oxygen concentration in the constructed wetland has not been fully studied. In this paper, the experimental device of constructed wetland is taken as the research object, through the alternation of dry and wet regulation to improve the internal oxygen state of wetland, the change of dissolved oxygen concentration in different substrate types of constructed wetland under the alternation of dry and wet at different temperatures and the influence of different dry and wet ratio on the dissolved oxygen concentration are analyzed systematically, in order to provide theoretical reference for the optimal design of constructed wetland ecosystem Guide.

Materials and methods

Experimental design

The constructed wetland experimental device is mainly composed of raw water tank and substrate reactor, and the experimental device is placed in a constant temperature box for control, Water Environment Laboratory, Hebei Provincial Academy of Ecological and Environmental Sciences, China (*Figure 1*).

a) Device structure: the size of the experimental device is 100 mm×100 mm×500 mm, which is divided into six groups of devices, three in each group are parallel, which are respectively completed in three thermostatic boxes. The water is supplied by the raw water tank in a unified way, each device is separately discharged, and the water in and out is controlled by the control valve.

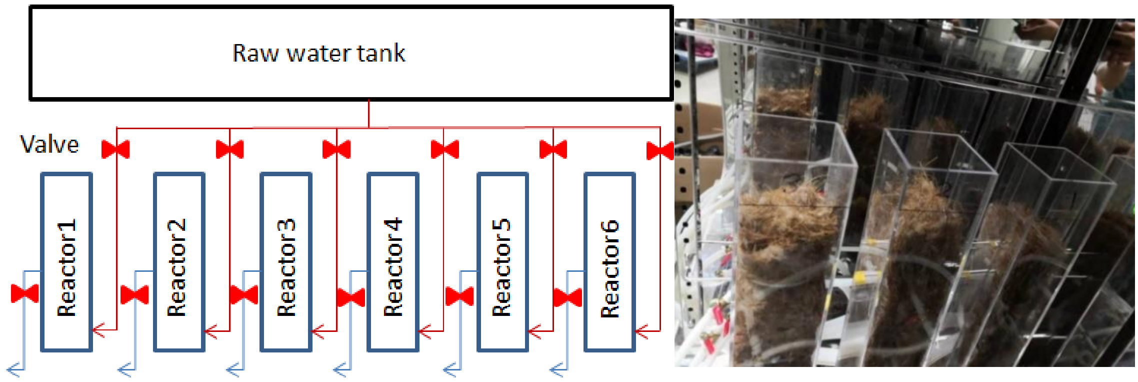

Figure 1. *Experimental device diagram*

b) Matrix: biocarbon matrix (reactor1-3, organic fiber material), size 100 mm×100 mm×50 mm; gravel (reactor4), particle size 10-20 mm; zeolite (reactor5), particle size 20-40 mm; volcanic rock (reactor6), particle size 20-30 mm.

c) Single structure: the biological carbon matrix adopts the "honeycomb" structure, i.e. the three-dimensional network structure, which is composed of straw and coconut fiber matrix, and is placed in unit 1-3 in three types respectively; gravel, zeolite and volcanic rock are placed in unit 4-6, respectively.

d) Water distribution mode: the raw water in the water tank enters the reactor from the bottom through the control of the inlet water level valve, and the outlet water level is controlled by the outlet valve.

e) Raw water: the raw water comes from the tail water of a sewage treatment plant in Shijiazhuang, Hebei Province, China. The tail water is regularly transported back to the laboratory through a transport vehicle in a bucket for standby.

f) Dry and wet alternation time (DAWT): 4 h, 8 h and 12 h, respectively.

Operation

1) *Table 1* shows the dry and wet alternative operation mode.

Table 1. *Operation mode*

No.	DAWT	Inlet/outlet mode	Control condition
1	4h	The dry/wet interval is 4h, i.e. the first hour is full of water, the fourth hour is 1/2V, the eighth hour is 1/2V, the 12th hour is 1/2V, the 16th hour is 1/2V,…	The samples were collected and analyzed at 10°C, 20°C, 30°C, and 20days after stable operation
2	8h	The dry/wet interval is 8h, i.e. the first hour is full of water, the eighth hour is 1/2V, the 16th hour is 1/ 2V, the 24th hour is 1/2V, the 32th hour is 1/2V,…	
3	12h	The dry/wet interval is 12h, i.e. the first hour is full of water, the 12th hour is 1/2V, the 24th hour is 1/2V, the 36th hour is 1/2V, the 48th hour is 1/2V,…	

2) *Table 2* shows the Operation mode of different operation cycle (dry wet ratio).

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Table 2. *Dry wet ratio operation mode*

No.	DAWT	inlet/outlet mode	Control condition
1	4h	The ratio of dry / wet time is 1h:3h, i.e. the control water volume is 1/2V from 0 to 1h, then the instantaneous water inflow is 1/2V, the instantaneous water outflow is 1/2V from full water level to 4h, the instantaneous water inflow is 1/2V from 1/2V to 5h, and the instantaneous water outflow is 1/2V from full water level to 8h,…	The samples were collected and analyzed at 10℃, 20℃, 30℃ ,and 20days after stable operation
2	8h	The ratio of dry / wet time is 2h:6h, i.e. the control water volume is 1/2V from 0 to 2h, then the instantaneous water inflow is 1/2V, the instantaneous water outflow is 1/2V from full water level to 8h, the instantaneous water inflow is 1/2V from 1/2V to 10h, and the instantaneous water outflow is 1/2V from full water level to 16h,…	
3	12h	The ratio of dry / wet time is 4h:8h, i.e. the control water volume is 1/2V from 0 to 4h, then the instantaneous water inflow is 1/2V, the instantaneous water outflow is 1/2V from full water level to 12h, the instantaneous water inflow is 1/2V from 1/2V to 16h, and the instantaneous water outflow is 1/2V from full water level to 24h,…	

Analysis index and methods

1) Do is determined by thermo Orion five star portable tester (Thermo Fisher Scientific Inc., American), NH_3-N, NO_3-N, NO_2-N, TN and other chemical indexes are determined according to the national standard method (State Environmental Protection Agency).

2) Sampling time: The experiment was carried out in July-October 2019. The samples were collected at 10℃, 20℃ and 30℃ for 20 days, and three samples were collected for each time.

3) The results were statistically processed using one-way ANOVA, assuming the significance level of α=0.05, with Origin version8.0. The Spearman correlation analysis was carried out by using the SPSS20.0.

4) Water quality sampling: Sampling ports were set at 40 cm in the lower layer of the reactor in the routine experiment; and at 10 cm in the upper layer, 15 cm in the middle layer and 40 cm in the lower layer of the reactor in the vertical experiment.

5) DO Sampling: The probe of portable detector was placed at 40 cm in the lower layer of the reactor in the conventional experiment; and, the probe was placed at 10 cm in the upper layer, 15 cm in the middle layer and 40 cm in the lower layer of the reactor in the vertical experiment.

Result

DO concentration change

Change of dissolved oxygen with temperature at different dry / wet intervals

It can be seen from *Figure 2* that in the constructed wetland experimental device, the DO concentration value in each substrate increases with the decrease of temperature (DO change value < 3 mg/L) at 4 h and 12 h of DAWT, while the DO concentration value in each substrate does not change significantly with the change of temperature at 8 h of DAWT. At the same time, the DO concentration in biochar matrix (1, 2, 3) is lower than that in common matrix (gravel, zeolite, volcanic rock) (DO change value < 3 mg/L). At

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this time, under the dry and wet alternate condition, reducing the time of dry wet alternation (i.e. accelerating the frequency) is conducive to the improvement of wetland reoxygenation capacity (DO change value < 3 mg/L).

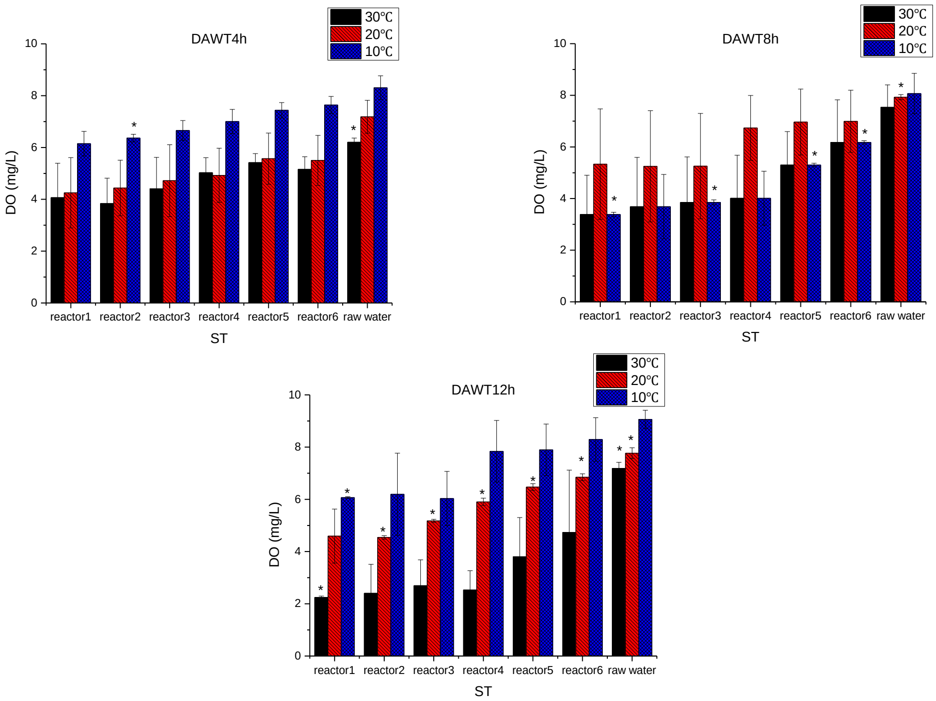

Figure 2. *Change of dissolved oxygen with temperature (*, a=0.05; n=9)*

Change of dissolved oxygen with dry/wet interval time at different temperatures

It can be seen from *Figure 3* that at low temperature of 10°C, the concentration of DO in each matrix does not change significantly at 4 h and 12 h of DAWT, but decreases at 8 h of DAWT (DO change value < 3 mg/L); At 20°C, the concentration of DO in each matrix does not change significantly with the time of DAWT; At 30°C, the concentration of DO in each matrix does not change significantly. The concentration of oxygen (DO) decreased with the increase of DAWT time (DO change < 3 mg/L). At the same time, DO concentration in biochar matrix (1, 2, 3) is lower than that in common matrix (gravel, zeolite, volcanic rock). It is also found that reducing the dry wet alternate time (fast increase frequency) is conducive to the improvement of wetland reoxygenation capacity (DO change value < 3 mg/L) under low temperature.

Change of dissolved oxygen in profile

It can be seen from *Figure 4* that at low temperature of 10°C, the concentration of DO in the bottom of each matrix is less than the upper value, that is, DO decreases with the increase of depth (DO change value < 1.5 mg/L).

Change of dissolved oxygen under different dry wet ratio

In order to study and analyze the change of dissolved oxygen under different operation cycles (dry to wet ratio, D/W ratio), only biochar matrix is selected for comparative analysis.

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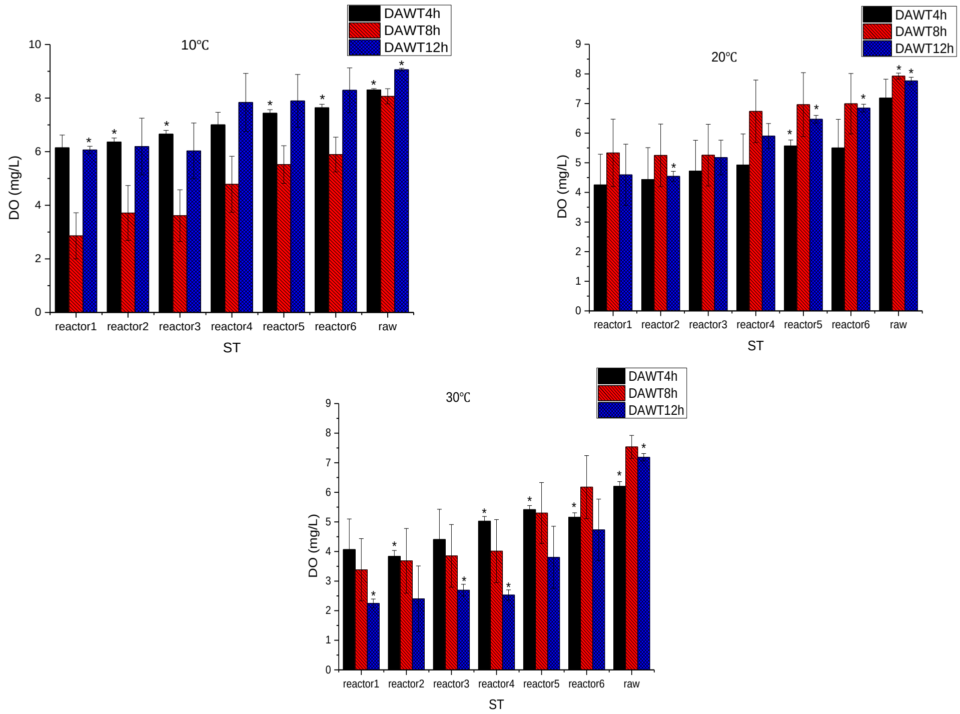

Figure 3. *Change of dissolved oxygen with dry wet alternation time (*, a=0.05; n=9)*

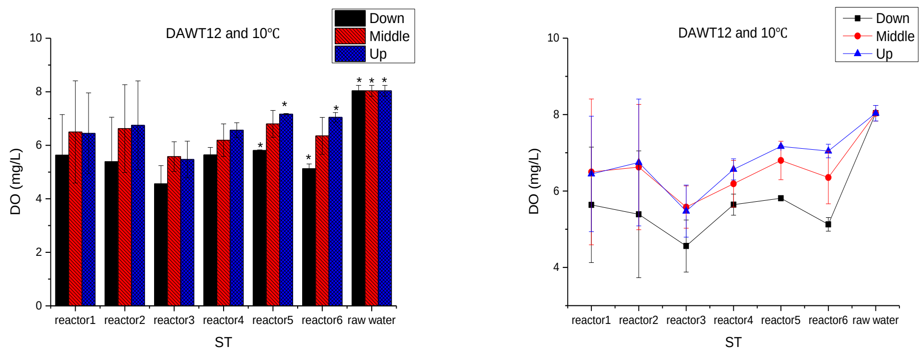

Figure 4. *Change of dissolved oxygen in profile (*, a=0.05; n=9)*

It can be seen from *Figure 5* that the concentration value of DO in the substrate does not change significantly (DO change value is less than 1.5 mg/L) compared with the concentration value in the original water at the dry wet alternation (DAWT) 4 h (dry wet ratio 1 h:3 h, 2 h:2 h, 3 h:3 h), 8 h (dry wet ratio 2 h:6 h, 4 h:4 h, 6 h:2 h), 12 h (dry wet ratio 4 h:8 h, 4 h:6 h, 8 h:4 h).

When the temperature is 30°C, the DO concentration in the substrate decreases first and then increases with the time of DAWT; At 20°C, the DO concentration in the substrate increased first and then decreased with the time of DAWT; At the temperature of 10°C, the DO concentration in the substrate decreased with the increase of DAWT. At all of the temperature, the DO concentration in the substrate with the dry wet ratio of 3 h:1 h is higher than that in the other substrate. At the same time, it is found that the DO concentration in the biochar matrix increased with the increase of the ratio of dry to wet

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(do change value < 1.5 mg/L). It is also found that under the low temperature condition, reducing the alternate time of dry to wet (fast increase frequency) and increasing the ratio of dry to wet time arw beneficial to the improvement of the wetland's reoxygenation capacity (DO change value 1.5 mg/L).

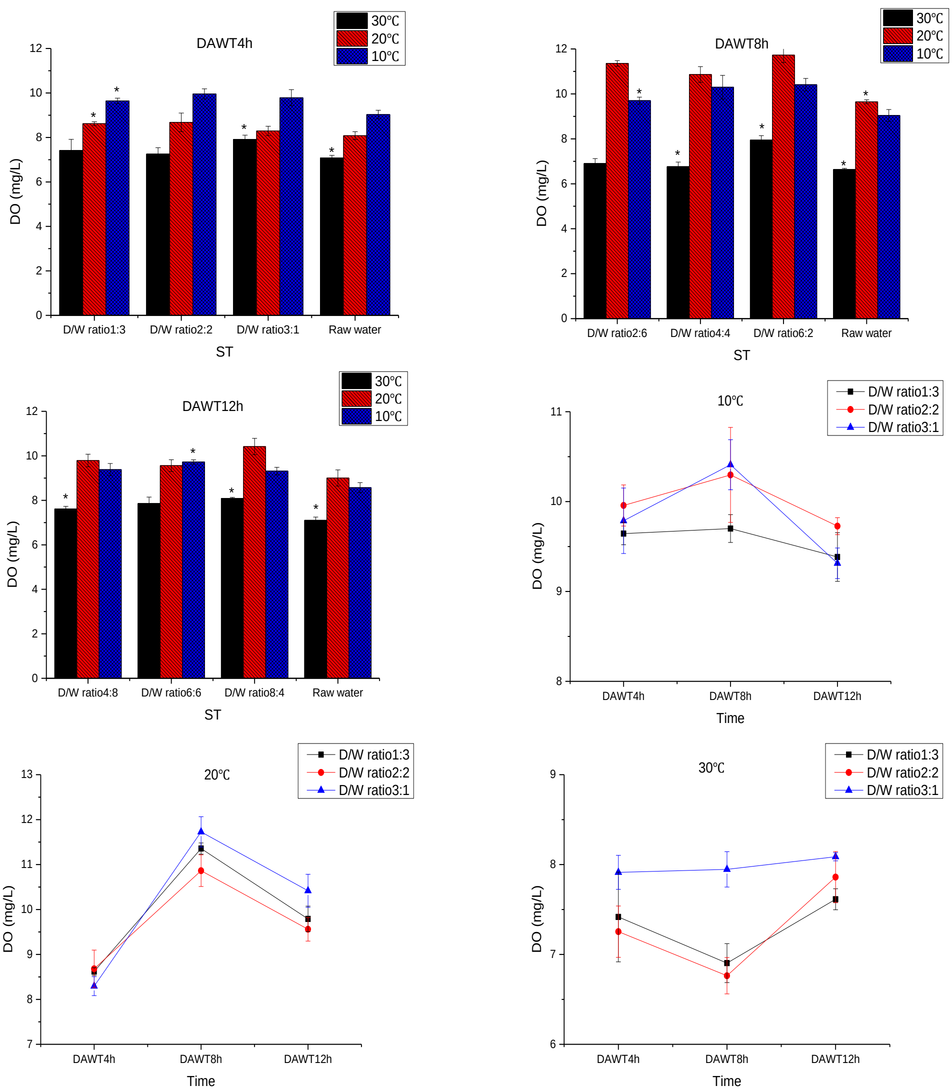

Figure 5. *Change of dissolved oxygen under different dry wet ratio (*, a=0.05; n=9)*

The relationship between dry wet alternation time and DO response

It can be seen from *Table 3* that under the influence of alternation of dry and wet in constructed wetland, DO in each substrate is significantly correlated with the interval of dry and wet for 12 h (Pearson correlation, $P<0.01$), and DO in biocarbon matrix 2, gravel, zeolite and volcanic rock matrix is significantly correlated with the interval of dry and wet for 4 h (Pearson correlation, $P<0.05$), but not in other cases. And DO in crushed stone matrix is significantly correlated with temperature of 30°C (Pearson correlation, $P<0.05$), but not in other cases.

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Table 3. *The relationship between DAWT and DO response*

Dry and wet conditions		Matrix type					
		Biochar1	Biochar2	Biochar3	Gravel	zeolite	volcanic rock
DAWT	4h	-0.578	-0.753*	-0.624	-0.667*	-0.741*	-0.794*
	8h	0.111	-0.006	0.054	-0.178	0.067	0.088
	12h	-0.908**	-0.794*	-0.814*	-0.923**	-0.760*	-0.701*
Temperature	30℃	-0.525	-0.381	-0.456	-0.677*	-0.479	-0.097
	20℃	0.085	0.029	0.126	0.326	0.331	0.486
	10℃	-0.020	-0.041	-0.164	0.213	0.150	0.223

Note: n = 9; *, significant correlation at 0.05 level (bilateral); **, significant correlation at 0.01 level (bilateral)

Discussion

Generally, in natural wetlands, through the natural vegetation, substrate and water level fluctuations and other factors, can achieve the aerobic environment, anaerobic environment and facultative environment alternately, that is, it provides the conditions for the survival of aerobic and ANAEROBIC microflora in wetland, and is beneficial to the removal of pollutants (Faulwetter et al., 2009; Jiang et al., 2019). The dissolved oxygen (DO) content in constructed wetland can be changed by Water / Hydrology Regulation, which makes it appear dry-wet alternate (Anaerobic / Aerobic Environment Alternate). Therefore, wet-dry alternation is an effective method to realize aerobic and anaerobic environment in constructed wetland.

The concentration of dissolved oxygen in wetland is low, which greatly limits the purification space of wetland and leads to the unsatisfactory decontamination effect because of the limitation of wetland structure (Van-Oostrom and Russell, 1994; Wu and Franz, 2001). It has been studied that the reaeration efficiency and the wetland treatment effect can be improved when the dry-wet ratio is 1:2 (8 h:12 h) (Shi et al., 2015). We find that the dry-wet alternate operation mode adopted in this paper can effectively increase the dissolved oxygen (DO) content in the wetland, and the DO concentration in the substrate at the dry-wet ratio of 3:1 (3 h:1 h/6 h:2 h) is higher than that at other dry-wet ratios. The reason is that increasing the dry-wet time ratio, that is, increasing the time of the substrate exposed to the air, so that more oxygen in the air into the wetland substrate. Therefore, wet-dry alternation is an effective method to realize the reoxygenation of constructed wetland.

It was found that the dissolved oxygen content was the main factor affecting the removal rate of pollutants in constructed wetlands (Maltais-Landry et al., 2009), because oxygen content directly affected the biochemical pathways of pollutants in different reduction states (Liu et al., 2017). It is reported that the oxygen output of plants is only1~8 g/(m^2g), and the lack of oxygen supply becomes the speed-limiting step of pollutant removal (Zheng et al., 2011). The dry-wet alternate operation mode adopted in this paper is an important technology to effectively improve the removal efficiency of organic matter in constructed wetland (Ding et al., 2015). The results showed that the DO concentration decreased with the increase of dry-wet alternate time (DAWT), that is to say, reducing the dry-wet alternate time could increase the DO content in constructed wetland and promote the removal of pollutants (Zhao et al., 2011).

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Through the significance analysis (*Table 3*), it is found that the alternation of dry and wet can significantly affect and improve the content of DO in the wetland matrix, and can realize the artificial aerobic, and create an aerobic environment for the wetland system microorganisms (Liu et al., 2017; Huang, 2018; Kang et al., 2019). In this study, it is found that temperature has no obvious effect on DO content.

Conclusions

(1) It can be concluded from the study of the incubator constructed wetland experimental device that DO concentration in all substrates increases with the decrease of temperature in different DAWT at 4 h, 8 h and 12 h, and decreases with the increase of DAWT at 10℃, 20℃ and 30℃ in different temperature. The concentration of DO in biochar matrix (1, 2, 3) is lower than that in common matrix (gravel, zeolite, volcanic rock). At this time, under the dry and wet alternate condition, reducing the time of dry wet alternation (i.e. accelerating the frequency) is conducive to the improvement of wetland reoxygenation capacity.

(2) It was found that the concentration of DO in biomass matrix did not change significantly in 4 hours (1 h:3 h, 2 h:2 h, 3 h:3 h), 8 hours (2 h:6 h, 4 h:4 h, 6 h:2 h), 12 hours (4 h:8 h, 4 h:6 h, 8 h:4 h) of DAWT. At different temperatures of 30℃, 20℃ and 10℃, the DO concentration in the matrix increased with the increase of the ratio of dry to wet time. In addition, the DO concentration in the substrate with the dry wet ratio of 3 h:1 h is higher than that in the other substrate. It is also concluded that reducing the frequency of dry wet alternation and increasing the ratio of dry wet time are conducive to the improvement of wetland reoxygenation capacity at dry and wet alternate condition (DO change value < 1.5 mg/L).

(3) In the study of constructed wetland profile at low temperature of 10℃, it was found that the concentration of DO in the bottom of each substrate was lower than that in the upper part, that is, the do value decreased with the increase of depth.

(4) It is found that the alternation of dry and wet can significantly affect and improve the content of DO in the wetland matrix, and can realize the artificial aerobic, and create an aerobic environment for the wetland system microorganism. It is also found that temperature has no obvious effect on DO content.

(5) What is the dynamic change of dry-wet time ratio and DO concentration under the condition of dry-wet alternation? And how to optimize the design of pollutants removal effect? And other issues need to be further studied.

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