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The Influence of Particle Sizes and Inlet-Outlet Configuration on The Hydraulic Characteristics of Horizontal Subsurface Constructed Wetlands

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Abstract. The objective of this study was to evaluate the influence of inlet and outlet location and matrix particle size on the hydraulic efficiency of horizontal subsurface constructed wetlands. A quasi-two-dimensional model was set up to evaluate its hydraulic efficiency by salt tracer test, and the change of flow state in the system was observed by dye tracer test. Three inlet and outlet settings: top inlet-bottom outlet, middle inlet-middle outlet and bottom inlet-top outlet; three particle size distributions are 3 mm, 5 mm and 3/5 mm (one half part 3 mm, the other 5 mm). According to the tracer test, the position of inlet and outlet and the size distribution of matrix have an effect on the hydraulic characteristics of constructed wetlands. Larger substrate size with bottom inlet–top outlet configuration could improve hydraulic behaviour, improve water treatment efficiency.

1. Introduction

In this study, effects of particle sizes, inlet -outlet configuration Horizontal subsurface flow constructed wetland, a water treatment technology, uses the substrate, microorganisms and plants to remove pollutants by physical, chemical and biological treatment [1-3]. It not only has the advantage of low treatment cost, but also has high removal rate of nitrogen, phosphorus, organic matter and pathogen [4-6]. In the subsurface flow constructed wetland, hydrodynamic conditions can change the physical and chemical properties, as well as determine the interaction time among pollutants in the water flow and matrix, plant roots, microbial population and hydraulic efficiency [7-9].

In constructed wetlands, different configurations can change the hydraulic performance. The inlet and outlet configuration influence the flow path to form dead zone. The influence of filter size on flow distribution is mainly shown in priority path and dead zone; a larger flow distribution can be obtained by increasing the number of packing sections. In general, the hydraulics of constructed wetlands can be evaluated by numerical simulation. A quasi-two-dimensional (2d) plexiglass boxes, filled with colourless glass beads, as miniature artificial wetlands [10-12].

In this study, effects of inlet-outlet configuration, filter size may lead to change hydraulic efficiency. A quasi-two-dimensional box was established for NaCl tracer and dye tracer experiments. The NaCl tracer test was used to calculate the hydraulic efficiency, and the dye tracer test was used to visualize the propagation of tracer in porous media reactor, the law of the internal hydraulic performance of constructed wetlands can be revealed.

2. Test Set

The horizontal subsurface flow constructed wetland, made of plexiglass, 400 mm×200mm×10mm (length × width × height). One side of the device there were three inlets, and the other side three outlets (Figure 1). Water distribution area and catchment area set the sponges (size 200mm×10mm×10mm, simulated porous media. The inside of device was full of glass beads which were simulated the substrates. The glass beads had two size, 3 mm and 5 mm. There are three filling modes: 3 mm (porosity 25%), 5 mm (porosity 36%), another is 5 mm glass beads at the bottom, 3 mm glass beads at the top (porosity 30%). The device is 10 mm thick, approximately two-dimensional.

3. Tracer Experiments

The tracers used were NaCl and Rhodamine B. Dissolved NaCl 0.5 g in 10 ml of water. The constant flow pump (Baoding Lange BT300-2J) was used to inject NaCl solution at a constant speed of 25r/min to the device. Water conductivity was measured by Conductivity meter (HQ14d) every minute. 0.2 g Rhodamine B was soluble in 20ml water, after the solution entered the installation, take pictures every 10 seconds.

4. Hydraulic Parameters

According to the fluid reactor theory, in the pulse tracer experiment the concentration measured corresponds to the distribution density of hydraulic residence time. The measured conductivity is standardized by formula (1) [13-15].

$$N(t) = (C(t) - C_w)\frac{1}{\lambda_{Na^+} + \lambda_{Cl^-}} M Q_s \frac{1}{MI} \tag{1}$$

$C(t)$ conductivity at the outlet; C_w conductivity of wastewater composition; λ_{Na^+}+λ_{Cl^-} the molar conductivity limit, M the sodium chloride molar weight; Q_s the outflow rate; *MI* the total mass injected.

The theoretical residence time T_n, the ratio of the effective volume of constructed wetland to the flow.

$$T_n = V/Q \tag{2}$$

The actual residence time T_m is the centre of mass of the *N(t)* curve:

$$T_m = \int_0^\infty tN(t)\,dt / \int_0^\infty N(t)\,dt \tag{3}$$

The efficiency of hydraulic λ_t

$$\lambda_t = T_m/T_n \tag{4}$$

σ^2 is the variance of RTD, describes the proportions of hybrid system.

$$\sigma^2 = \int_0^\infty (t - T_m)^2 N(t)\,dt \tag{5}$$

σ_θ^2 is the standard variance of RTD variance normalized, a measure of the RTD distribution.

$$\sigma_\theta^2 = \sigma^2/\lambda_t^2 \tag{6}$$

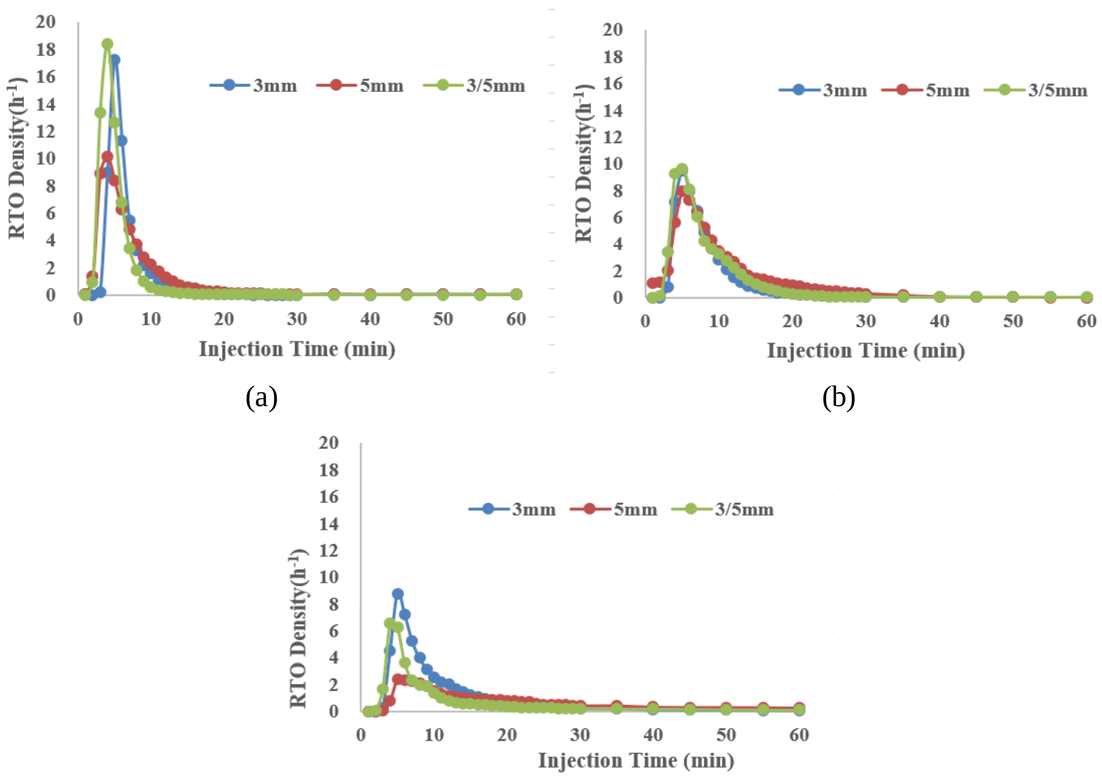
5. Results and Discussion

Under different particle size distribution, the order of actual hydraulic retention time is bottom-top > middle-middle > top-bottom (table 1). The same inlet and outlet, the actual hydraulic retention time sorting is 3/5 mm < 3 mm <5 mm, but the bottom-top 3 mm <3/5 mm <5 mm, because the water resistance from the bottom to the top in the process, from the big pores into small pores, , increased the head loss, smaller pore velocity, substrate in contact with the water flow more fully, the average hydraulic retention time is longer than the other. Bottom-top has the highest hydraulic efficiency.

The distribution of RTD density curve is consistent, all of them tend to 0 after reaching the peak value, and are bell-shaped with a long trailing tail (figure 1). The peak value of homogeneous matrix with 5 mm particle size was the smallest. In the middle-middle, the peak value of RTD density curve with different particle sizes was not significantly different, while the peak value of 3 mm and 3/5 mm was much higher than 5 mm in the other two inlet-outlet.

Table 1. The Hydraulic Parameters of the Different Substrate Sizes and Inlet-outlet Configurations

particle size	Inlet-outlet	Tm/h	Tn/h	λ_t	σ^2	σ_θ^2
	top to bottom	0.124		2.588	0.729	0.109
3 mm	middle to middle	0.143	0.0481	2.982	0.568	0.064
	bottom to top	0.206		4.276	1.565	0.086
	top to bottom	0.131		2.720	0.886	0.132
5mm	middle to middle	0.175	0.0693	3.644	1.039	0.078
	bottom to top	0.431		8.966	2.736	0.034
	top to bottom	0.087		1.808	0.308	0.046
3/5 mm	middle to middle	0.137	0.0587	2.847	0.565	0.070
	bottom to top	0.231		4.811	1.752	0.076



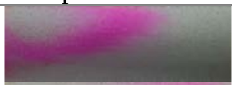
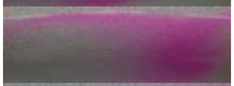
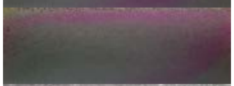
(a) (b) (c)

(a) Top inlet-bottom outlet (b) Middle inlet-middle outlet (c) Bottom inlet-top outlet

Figure 1. Breakthrough Curves of NaCl Tracer for Different Inflow Rates

The table 2 shows, for the same inlet-outlet, large size particles have large porosity, so dye diffusion speed fast; small size particles have small porosity, the flow diffusion has to overcome more resistance. Obviously 3/5 mm, middle to middle.

Table 2. Dye Tracer Propagation of the Different Substrate Sizes and Inlet-outlet Configurations

particle size	time	top to bottom	middle to middle	bottom to top
3 mm	2 min			
	4 min			
	6 min			
5 mm	2 min			
	4 min			
	6 min			
3/5 mm	2 min			
	4 min			
	6 min			

6. Conclusion

Among all kinds of inlet-outlet layouts, bottom-top set has longer flow, lower pore velocity, maximum average hydraulic retention time and hydraulic efficiency, while top-bottom set has shorter flow, minimum average hydraulic retention time and hydraulic efficiency. Larger size of matrix has larger porosity, long hydraulic retention time and high hydraulic efficiency.

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