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Coupling of the flow field and the purification efficiency in root system region of ecological floating bed under different hydrodynamic conditions*

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Abstract: The artificial ecological floating bed is a commonly adopted *in situ* treatment technique for repairing and purifying polluted water. The plant root system of the floating bed is the primary region to absorb and degrade the pollutant of water. Its inner flow field characteristics and the interactive water quantity with the surrounding water greatly impact the purification efficiency of the floating bed. In this paper, the particle image velocimetry (PIV) technology and the boundary velocity direct extraction method are used to study the velocity distribution of the root system region by numerical simulations and experiments in an experimental water channel. A pollution removal rate (PRR) evaluation model is built to calculate the PRR by coupling with the flow velocity field of the root system region. The variations of the total pollutant removal rate (TPRR) are discussed for different center distances ($L = 0.30$ m, 0.45 m, 0.60 m), flow velocities ($v = 0.007$ m/s, 0.015 m/s, 0.025 m/s, 0.040 m/s, 0.055 m/s, 0.070 m/s) and root system porosities ($P = 54.73\%$, 68.33%, 79.17%). The results indicate that the position arrangement of the floating beds influences the TPRR significantly, and the distance should be limited in a reasonable range for a high purification efficiency. Moreover, the root systems with higher porosity ($P = 68.33\%$, 79.17%) have higher TPRR value than a lower porosity root system ($P = 54.73\%$) within a certain flow velocity range, and the higher porosity root system has less fluctuation of the TPRR value than a lower porosity situation within a wide flow velocity range. Furthermore, under the same center distance condition, the lower flow velocity condition brings about a significantly higher TPRR value than the higher flow velocity situation.

Key words: ecological floating bed, root system region, flow velocity, pollutant removal rate, PIV

Introduction

The artificial ecological floating bed is widely used in various water bodies to treat polluted water. The pollutant in the water (such as Ammonia-Nitrogen) can be absorbed by the plant root system, and also can be degraded by the microorganisms that have parasitized the root systems. The implementation practice indicates that the ecological floating beds can effectively purify water and significantly enhance the self-repair ability of rivers and lakes[1,2]. In recent years, an immense amount of studies was carried out focusing on the influences of the plant type, the number of plants per unit area and the coverage rate on the pollutant removal rate (PRR)[4,5], as well as the influence of the shape of the floating bed and the arrangement mode on the river flow pattern [6,7].

The plant root system of a floating bed is the primary region to absorb and degrade the pollutant of water, and its inner flow field characteristics and the interactive water quantity with the surrounding water are closely related with the purification efficiency of

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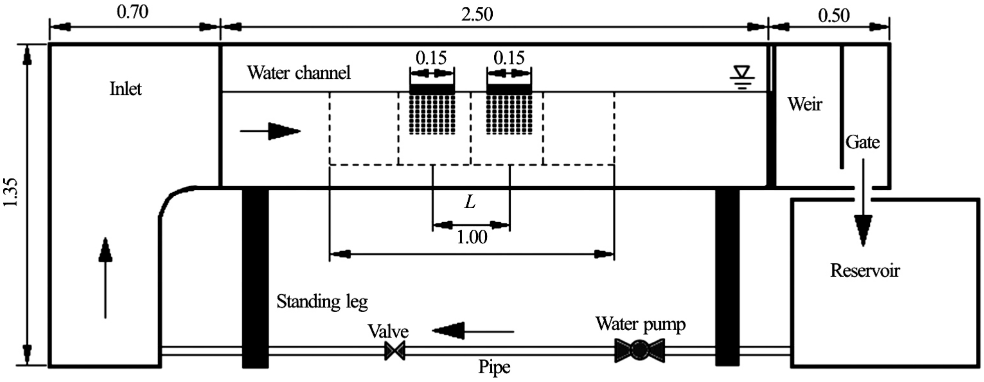

Fig.1 The dimension of water channel and experimental domain (m)

the floating bed. Many studies show that the quantity of the water flow and the hydraulic retention time (HRT) of the root system region are the main parameters to decide the PRR of the floating bed[8-10]. Generally, a larger water flow quantity can bring more pollutant through the root system region, which is beneficial to enhance the pollutant absorbing quantity by plants. However, the HRT decreases with the increase of the flow quantity, and a too short HRT is disadvantagious to the biochemical reaction process. Thus, the hydrodynamic characteristics of the root system region are the most important factor in the purification process of the floating bed. So far, little experimental and simulation studies of the flow field in the root system region have been carried out, especially those related with the coupling of the flow field and the purification efficiency of the root system region[11].

In this paper, the PIV technology and the boundary velocity direct extraction method are used to study the velocity distribution of the root system region by numerical simulations and experiments in an experimental water channel. Meanwhile, the pollution removal rate evaluation model is built to calculate the PRR by coupling with the flow velocity field of the root system region. The variations of the total pollutant removal rate (TPRR) are discussed for different center distances ($L = 0.30$ m, 0.45 m, 0.60 m), flow velocities ($v = 0.007$ m/s, 0.015 m/s, 0.025 m/s, 0.040 m/s, 0.055 m/s, 0.070 m/s) and root system porosities ($P = 54.73\%$, 68.33%, 79.17%).

1. Experimentation design

1.1 *Experimental equipment*

A rectangular section circulation water channel is used to simulate a natural river. The water channel is fixed on a steel frame base with a dip angle of 0.1° along the length direction. The water flow in the channel is driven by a circulating water pump, and the flow velocity in the channel can be controlled by the inverter motor driver and the accessory valve system. To eliminate the inlet velocity fluctuation, the water is pumped into the reservoir first and then flows into the water channel through an inlet weir gate between the reservoir and the channel. At the outlet side of the channel, a moveable outlet weir gate is used to control the water level of the channel (with the water depth of 0.40 m). Two floating beds are arranged in the middle region of the channel with the center distance of L. The 100cm middle section of the channel is selected as the experimental domain. The sketch of the experimental channel and the dimension of the experimental domain are shown in Fig.1.

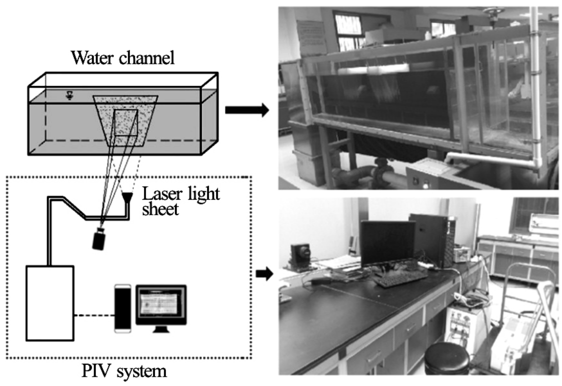

Fig.2 The experimental channel and the PIV system

To accurately measure the flow velocity field around the root system region, a particle image velocimetry (PIV) system is used, as shown in Fig.2. The laser light sheet is arranged under the water channel, which is overlapped with the middle longitudinal section of the channel. The camera is placed at the outside of the channel, perpendicular to the middle section of the channel. A few tracer particles are put into the circulation water, which can be illuminated by the laser light sheet, their positions can be captured by the camera and transformed to the real time flow velocity field[12]. Due to the limitation of the exposure area of